# APPLICATION OF THE RISK ASSESSMENT METHODOLOGY TO LEVEL CROSSING ACCIDENTS ON JR EAST

by

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## Abstract

In this thesis, the risk assessment methodology is applied to evaluate the safety of level crossings on the JR East network. The risk of a crossing accident is defined as the product of the likelihood of the accident (or the accident rate per million trains) and the expected consequences per accident. This definition of risk is extended to include the perceptions associated with catastrophic consequences and the willingness-to-pay values of the consequences and is referred to as the monetary collective risk $R_m$.

Rail traffic volume, road traffic volume, visibility of the crossing, road gradient, crossing width and the level of safety are shown to influence the accident rate and the collective risk $R_m$. The mean accident rate at all crossings is 0.74 per million trains, at crossings equipped with barriers is 0.59, at crossings equipped with warning bells is 1.25 and is 0.76 at pedestrian crossings. Crossings equipped with obstacle detectors have a lower accident rate (0.12) than crossings without detectors (0.43). Crossings with visibility less than 20 m have a 50% higher mean accident rate than crossings with visibility greater than 20 m. At crossings with high rail traffic volume in urban areas, the consequences of train delays and cancellations are an order of magnitude higher than the consequences of fatalities and injuries.

The human factors of the road driver is found to be an important component of crossing accidents. A model which defines a "risk parameter" to account for the human factors and also includes specific crossing attributes is developed to predict the accidents. Risk management techniques are applied to determine the efficacy of various level crossing safety devices. Finally, a Risk Management Plan is developed for JR East to determine efficient allocation of resources for level crossing safety.

Thesis Supervisor: Carl D. Martland
Title: Senior Research Associate

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# Chapter 1

# Introduction

## 1.1 Level crossing safety

This thesis analyzes level crossing accidents on JR East[1] using the techniques of probabilistic risk assessment. Since its formation from Japan National Railways (JNR) in 1987, a total of 927 accidents have occurred on the 7894 crossings present on the system as of March, 1993. This research was done under the aegis of the cooperative research effort between MIT and JR East in the area of risk assessment.

## 1.2 The JR East Risk Assessment Project

The collaborative research effort between JR East and MIT began in January 1992 when Mr.Makoto Shimamura of the Safety Research Laboratory of JR East came to MIT to study at the Center for Advanced Engineering Studies. He became interested in the applications of probabilistic risk assessment to the daily operations of JR East and discussed the research agenda with the MIT faculty. This set the stage for the cooperative effort.

[1]Throughout this thesis, JR East refers to East Japan Railway Company.

### 1.2.1 Projects in the area of risk assessment

The first year research in the area of risk assessment commenced in September, 1993. It was very productive and yielded four working papers:

1. Risk Assessment on the Amtrak Train Crash of September, 1993
2. A Framework to Measure the Safety Performance of a Railway Company
3. Preliminary Analysis of Level Crossing Accidents
4. Estimating the Probability of Rare Events

The preliminary analysis of the level crossing accidents was done by Dr.Ármann Ingólfsson [8]. This yielded some very interesting results. For instance, it showed a dramatic decrease in the number of accidents since 1987, indicating the success of the JR East investment in level crossing safety.

The second year program in the area of risk assessment commenced in September, 1994 and identified new areas of research in addition to some continuing research topics. The two continuing topics of research were: Level Crossing Accidents and Safety Performance Index. Two new research areas which were identified were: Risks from Natural Hazards and Human factors in Risk Assessment. We have been continuing the research related to level crossing safety since September, 1994.

### 1.2.2 Level crossing safety on JR East

Since its inception from Japan National Railways (JNR) in 1987, JR East has given top priority to the safety of its complex network. The Safety Research Laboratory, established in April 1989, carries out research in a variety of topics related to railroad safety such as level crossing accidents, accidents due to natural hazards, human factors, train control etc.

A team of JR East people work specifically in the area of level crossing safety in the Safety Research Laboratory. They are researching the application of better quality safety devices such as level crossing barriers and obstacle detectors at level crossings.

In addition, they determine potential crossings which can be upgraded to a higher level of safety by installing safety devices at the crossing. The group is also developing computer models to simulate better visibility of the crossings. These models incorporate bright markings on the road leading to the crossing, roughening roads having downward gradient so that vehicles don't slip at the crossing and installing overhanging signs at low visibility crossings.

The work of the level crossing group is backed by the other employees of JR East who try to ensure the safety of the crossings. Rigorous training programs at train control centers train drivers to respond to a variety of emergency situations at level crossings. The train control center at Tabata hosts four simulators which simulate different accident scenarios at level crossings and train personnel to respond instantly to these emergencies.

The company also advertises in the media about the dangers of illegal crossing. Posters put up in railway stations and trains talk about the installation of various safety devices at level crossings.

## 1.3 Level crossing safety in the US

Level crossing safety is of critical concern in the United States, as almost half of the rail related deaths result from level crossing accidents. In 1993 alone, these accidents resulted in 517 fatalities and 1,677 injuries at public crossings. At present, there are a total of 168,000 public level crossings. To reduce level crossing accidents, a program called the Rail-Highway Crossing Program (or the section 130 program) was established as part of the Highway Safety Act of 1973. This program provides federal support to the states so that they can improve their public crossings and reduce the number of accidents occurring at these crossings [21]. The different methods to improve crossings are:

- Separate the crossings by building overbridges or underpasses.

- Install warning devices at the crossings.

- Close the crossings.

A number of organizations are involved in the effort to improve the safety of level crossings. The Federal Highway Administration (FHWA), the Federal Railroad Administration (FRA) and the National Highway Traffic Safety Administration (NHTSA) are the three Department of Transportation (DOT) agencies which oversee the issue of crossing safety at the federal level [21]. The FHWA implements the Rail-Highway Crossing Program, the FRA is responsible for railroad safety and the NHTSA funds education programs for road drivers about driving behavior. A private organization, Operation Lifesaver, promotes level crossing safety by education and law-enforcement efforts [21]. It is supported by federal and railroad funds and is a very strong operator in trying to improve level crossing safety.
The number of crossing accidents has declined significantly since the Rail-Highway Crossing Program began in 1974. But, most of the reduction has come about in the first ten years of the program (till 1985) and little decline has occurred after that. During this period, the number of crossings also declined from 219,161 in 1975 to 168,116 in 1993 [21].

### 1.3.1 Estimating the safety of level crossings

Several researchers have worked on various methods to predict the safety of a level crossing. In the United States, empirical formulae have been used to predict the expected accident rate at a level crossing. These formulas consider the accident history as well as some of the causal factors in determining the accident rate at a particular crossing. Most of the formulas determine the hazard index which can be used as a basis to measure the number and severity of the accidents. A few of the formulas are discussed below.

1. The Peabody and Dimmick Formula [18]: This formula predicts the expected number of accidents in 5 years, $A_5$ as

$$A_5 = \frac{1.28V^{0.170} + T^{0.151}}{P_c^{0.171}} + K \tag{1.1}$$

where

$V$: Average 24 hour traffic volume

$T$: Average 24 hour train volume

$P_c$: Protection coefficient

$K$: Additional parameter

2. The New Hampshire Formula [6]: The hazard index, $H.I$, is given as

$$H.I = VTP_f \tag{1.2}$$

where

$V$: Average 24 hour traffic volume

$T$: Average 24 hour train volume

$P_f$: Protection factor

3. The Mississippi Formula [6]: The Hazard index, $H.I$, is given as

$$H.I = \frac{SDR/8 + A_5}{2} \tag{1.3}$$

where

$SDR$: Sight distance rating

$A_5$: Expected number of accidents in 5 years

4. The Ohio method [6]: The hazard index, $H.I$, is given by

$$H.I = A_f + B_f + G_f + L_f + N_f + SDR \tag{1.4}$$

where

$A_f$: Accident probability factor

$B_f$: Train speed factor

$G_f$: Approach gradient factor

$L_f$: Angle of crossing factor

$N_f$: Number of tracks factor

$SDR$: Sight distance rating

5. The DOT Accident Prediction Formula [6]: This formula combines both the accident history for the crossing and the accident causal factors and defines the accident prediction as

$$A = \frac{T_0}{T_0 + T} \times (a + \frac{N}{T}) \tag{1.5}$$

where

$A$: Final accident prediction in accidents per year at the crossing

$a$: Initial accident prediction, which is defined as

$$a = K \times (EI) \times (MT) \times (DT) \times (HP) \times (MS) \times (HT) \times (HL) \tag{1.6}$$

where

$K$: Constant for initialization of factor values at 1.00

$EI$: Factor for exposure index based on the product of highway and train traffic

$MT$: Factor for number of main trains

$DT$: Factor for number of trains per day during daytime

$HP$: Factor for highway paved

$MS$: Factor for maximum timetable speed

$HT$: Factor for highway type

$HL$: Factor for number of highway lanes

$N/$T: Accident history prediction ($N$ accidents in $T$ years)

$T_0$: Formula weighting factor, given as

$$T_0 = \frac{1.0}{0.05 + a} \tag{1.7}$$

Of the five nationally recognized prediction formulas, namely the DOT formula, Peabody-Dimmick, NCHRP Report 50, Coleman Stewart and the New Hampshire formulas, the DOT accident prediction formula outperforms the others in terms of predicting the number of accidents that have occurred at all crossings [5].

Thus, most of the accident prediction formulas consider some of the important attributes of the level crossing in computing the hazard index. The DOT formula considers both the accident history as well as the crossing attributes in determining the accident prediction (number of accidents per year).

### 1.3.2 Strategies for improved level crossing safety

Many strategies can be employed to improve the safety of level crossings. They range from engineering approaches like installing warning bells and crossing barriers to enforcement and education efforts warning people about the dangers of illegal crossing.

### Engineering Approaches

The conventional approach used to improve the safety of crossings is to install warning bells and level crossing barriers. The barrier comes down before the train reaches the crossing, preventing any road vehicles from legally going into the crossing area. In addition, crossings can be installed with obstacle detectors and alarm buttons. Obstacle detectors detect the presence of any vehicles caught in the crossing and activate the railroad signalling system (Section 3.2.1). Alarm buttons act as an aid to the detectors and can be activated in the event of an emergency. At low visibility crossings, warning signs can be put up by the side of the road alerting the driver of the presence of a crossing ahead.

Grade separation is a viable solution to prevent illegal crossings, but is much more expensive than installing warning devices [21]. Hence, it is not used often.

The Department of Transportation (DOT) is funding the research on new technologies to improve crossing safety [21]. Some of the technologies are discussed below:

1. The Friendly Mobile Barriers System [21]: This system consists of a barrier that rises up from the road after the level crossing gates have come down. Thus, it can prevent any vehicle from going into the crossing area. The barrier is designed to absorb the energy of a vehicle striking it, thereby avoiding serious injuries to the occupants of the vehicle.

2. The Illinois Dragnet Arresting System [21]: This system consists of a net which can be lowered from roadside towers and acts as a barrier in addition to the existing barriers at the crossing.

Neither of the systems have been tested in actual conditions, but it is believed that they will be cheaper than grade separating the crossing and more expensive than installing the warning system [21].

### Education and enforcement

The existing engineering solutions to improve crossing safety have a limit to their effectiveness, since they cannot prevent road vehicles from illegally driving into the crossing. Strict enforcement by the authorities can help in reducing the number of illegal crossings. But this by itself is not a solution. For instance, half the level crossing accidents on the JR East network are due to illegal crossings (ignoring the warning bell or intrusion against the level crossing gate) even though a fine of 10,000 yen is levied on drivers who illegally go across. Enforcement coupled with active education campaigns can effectively reduce the number of illegal crossings. Operation Lifesaver has been doing a tremendous job in the US educating people about the consequences of violating crossing warning signs.

Thus, engineering approaches, both conventional and innovative, along with effective education and enforcement can reduce the number of crossing accidents.

## 1.4 Motivation

The impetus for our work lies in the concern that the Safety Research Laboratory of JR East expressed regarding the issue of level crossing safety. They were interested in the causal factors of accidents and the relative importance of the different crossing attributes in determining the accident rate. Their other concern was identifying crossings that need to be upgraded to a higher level of safety because of their likelihood of having accidents.

The probabilistic risk assessment methodology is a tool which can be effectively utilized to address their concerns. It addresses the risk of a level crossing accident as the product of the likelihood of occurrence of an accident and the expected consequences of that accident. The accident rate (or the likelihood) quantifies the importance of the various level crossing attributes and determines whether they are significant. The effectiveness of the various safety devices at the crossing can be determined by looking at the risk values for crossings equipped with the different devices. The issue of perceived risk can be addressed in the context of the likelihood of catastrophic accidents. Finally, potential crossings which need to be upgraded can be identified by the risk cost criterion.

## 1.5 Organization of the thesis

The organization of the thesis is as follows:

Chapter 2 talks about the risk assessment methodology. We give the various definitions of risk and present the three components of the risk assessment methodology, namely risk analysis, risk appraisal and the optimal allocation of resources. Risk analysis is the technical component of risk assessment and involves the application of concepts from the fields of engineering and probability theory. Risk appraisal talks about value judgments and discusses the perceptions of risk. Factors affecting the perceptions of risk are evaluated and the definition of risk is extended to include these perceptions. The way in which information about safety is transmitted to the public is also discussed. Finally, the issue of the optimal allocation of resources is presented in the context of the limited availability of resources for safety. The question that is addressed is the following: How do we allocate the resources such that we can achieve the greatest reduction in risk? The condition for the optimum investment level is also presented.

In Chapter 3, we carry out the exploratory analysis of the level crossing and accident databases. Specifically, we look at some of the important level crossing attributes which affect the number of accidents at the crossing. The risk assessment methodology is developed for the level crossing accidents on JR East by defining the accident rate and the consequences of the accidents. The accident rates and the monetary collective risk are determined for crossings equipped with the various safety devices by type of road traffic involved in the accident. The efficacy of the safety devices in reducing the risk of the accidents is also illustrated. Finally, a brief discussion on the possibility of catastrophic level crossing accidents is presented.

In Chapter 4, we develop a risk model to predict the accidents occurring at the crossing. This model is a behavioral model and considers the characteristics of the crossing as well as the human factors involved in crossing accidents. We also come up with order of magnitude estimates for the likelihood of a vehicle going into the crossing area once the warning bell starts ringing and also when the barrier starts coming down.

In Chapter 5, we illustrate the risk management of level crossings by performing a cost-benefit analysis on the application of the various safety devices at the crossing. Cost-benefit analyses are also conducted to upgrade the safety of low visibility crossings and crossings with significant downward road gradient leading to the crossing. Sensitivity analyses is done by varying the value of life estimates and determining its effect on the efficacy of the safety devices. A Risk Management Plan for level crossing safety is presented to JR East.

Finally, the conclusions of the work is presented in Chapter 6 of the thesis.

# Chapter 2

# The Risk Assessment Methodology

## 2.1 What is risk?

There are very many different definitions of risk. Rowe [11] defines risk as "the potential for unwanted negative consequences of an event or activity" and refers to the notion of chance. Lowrance [11] explicitly accounts for the dichotomy in the definition of risk and refers to it as the "measure of probability and severity of adverse effects." Gratt [11] takes a similar stance as Lowrance and specifies the relationship between the probability and the adverse consequences by stating that the "estimation of risk is usually based on the expected result of the conditional probability of the event times the consequences of the event given that it has occurred." Wharton [11] states that "a risk is any unintended or unexpected outcome of a decision or course of action," including both positive and negative outcomes. Odoni [17] defines risk as "the average "cost" per unit of time due to the occurrence of unwanted events" and refers to it as the product of the number of accidents per unit of time and the average cost per accident. Thus, all of the above mentioned references to risk broadly define it as the product of the probability of occurrence of an event and its consequences, whether it be positive or negative.

Technological risk, which is a branch of man-made risk, has become an issue of concern in recent years. This importance can be attributed to the large improvements in science and technology. A noteworthy paradox is that while advances in technology occurred as a way to mitigate the risks, these advances themselves have become an issue of increasing risks to society. Nuclear spillage, industrial pollution, environmental degradation and radiation hazards are some types of technological risks. One of the reasons as to why technological risks are greatly feared is that they are relatively newer risks to society, as compared to natural risks like earthquakes and landslides. For example, Litai [13], in his research conducted at MIT in the late 1970s in the context of the safety of nuclear reactors, contends that a man-made risk is valued 20 times more than a natural risk. We will look at Litai's methodology and results in section 2.4.1. Thus, it sounds reasonable to look closely at technological risks posed to society at large.

Transportation risk is a type of technological risk. This risk can result from either of the three main modes of transportation: road, rail and air transportation. Two reasons can explain the increasing importance of transportation risk [16]:

1. The current transportation systems are highly sophisticated and have advanced technologies built into them. This creates the potential for greater risks due to higher levels of automation and the requirement of pin-point efficiencies.

2. The number of users of the system has increased. Even if the risk per user does not change, the collective risk of society increases due to the increased number of users.

## 2.2 Components of a Risk Assessment Study

As we described in the previous section, the issue of safety is very important for technical systems. Accidents in such systems are greatly feared, thus remedial measures need to be taken even before the accident occurs. The risk assessment methodology addresses just this issue. It poses the following question for a technical system: Is the system safe? [3] This question consists of two components:

1. What can happen?

2. What is acceptable?

The first question refers to risk analysis and falls under the domain of the technical componant of risk assessment. The second question refers to risk appraisal and involves value judgments and subjective guessing on the part of the team conducting the risk assessment study. It is well known that the risk of a technical system can be reduced to a negligible value, but can never be made equal to "zero." Absolute safety is an impossible thing to achieve. The limit on increasing safety doesn't come from safety itself, but from the resources that can be invested in safety. The resources available for investing in safety are limited. This can also be interpreted as the opportunity cost of investing in other areas. This limitation comes about because safety is not the only consideration in social welfare, other issues such as amenities and public goods are equally important. This leads us to the third component of risk assessment: Investing in safety. The question that is posed is the following: Given the limited resources available for safety, what is the optimal investment criterion such that we can minimize the risks that we have to live with? This should not be viewed as an avoidance of investing in safety, but rather as an attempt to allocate available resources in such a way that maximum benefit is achieved in terms of risk reduction.

## 2.3 Risk analysis

As mentioned in the previous section, risk analysis refers to the technical component of risk assessment. The outline of risk analysis is as follows:

1. Identify all the adverse events.

2. Determine the probability of occurrence of these events.

3. Determine the expected consequences of these events.

4. Multiply the probability of occurrence by the expected consequences.

5. Sum over all the events considered.

Let $i = 1, 2, 3 \ldots, n$ be all possible adverse events (i.e. the number of all the mutually exclusive accident scenarios.) Let $p_i$ be the probability of occurrence of event $i$ and $c_i$ be its expected consequence. Then, the collective risk $R$ is defined as:

$$R = \sum_{i=1}^{n} p_i c_i \tag{2.1}$$

The success of any risk analysis relies on an effective combination of various methodologies. These include a good engineering understanding of the system being evaluated, along with models from the domain of probability and statistics [17]. A description of the methodologies is given below:

- Engineering analysis: A thorough understanding of the system being studied is necessary so that the analysis can be addressed to the specific problems of the system.

- Probabilistic models: A few of the models used in risk assessment are given here. Risk assessment comes under the realm of realibility engineering, which deals with the probability and effects of system failures. When these system failures lead to untoward consequences in terms of human injuries and fatalities, it relates to the issue of safety. Another probabilistic model that is extensively used is fault trees. Finally, a relatively new concept being employed is "emergency response analysis" which talks about the specific emergency measures that need to be taken in the event of an accident.

At this stage, it is important to distinguish the notion of risk as it depends on the perspective being considered. Broadly, three perspectives come to the forefront in any risk assessment study: an individual who is exposed to the risk, the societal risk and the company which is responsible for the system creating the risk. Let us illustrate the three notions of risk with the example of a level crossing accident. An individual who goes across the level crossing assigns a certain probability to he being involved in an accident. This probability fully describes the risk to the individual from going across the level crossing. The individual is only concerned about his or her own risk, and does not care about what happens to other people. But society is concerned about what happens to a group of individuals as a whole. Here, the societal risk can be the total number of people who are injured or killed in level crossing accidents every year or per million trains going across the level crossing. This is simply the sum of all the individual risks and is defined by the collective risk R as shown in Figure 2-1. The company or agency has an additional issue to think about. It fears the occurrence of catastrophic accidents which are "low probability high consequence" accidents. At a level crossing, a catastrophic accident can occur as a result of a sequence of low probability events occurring in succession to result in the extremely undesirable event. Such accidents can damage the reputation of the company very badly and question its very existence. For example, a catastrophic level crossing accident occurred in Kasumbalesa in 1987 when a train collided with a large truck stuck at a crossing and resulted in 100 passenger deaths and 125 total fatalities. This is directly related to the notion of "perceived risk" that is discussed in the risk appraisal part of the risk assessment study.

## 2.4 Risk appraisal

This branch of risk assessment looks at the issue of acceptability of risk and involves value judgments. These judgments are not only confined to the domain of the technical expert, but involves people from all walks of life such as psychologists, sociologists, economists, politicians, laymen etc. The question of the acceptability of risk becomes tractable if quantitative values are assigned to it. But, assigning quantitative values is not trivial since the issue of risk appraisal involves psychological factors and they are difficult to quantify. Another issue that needs to be addressed in this context is the way in which ideas about risk are communicated to society, because the public

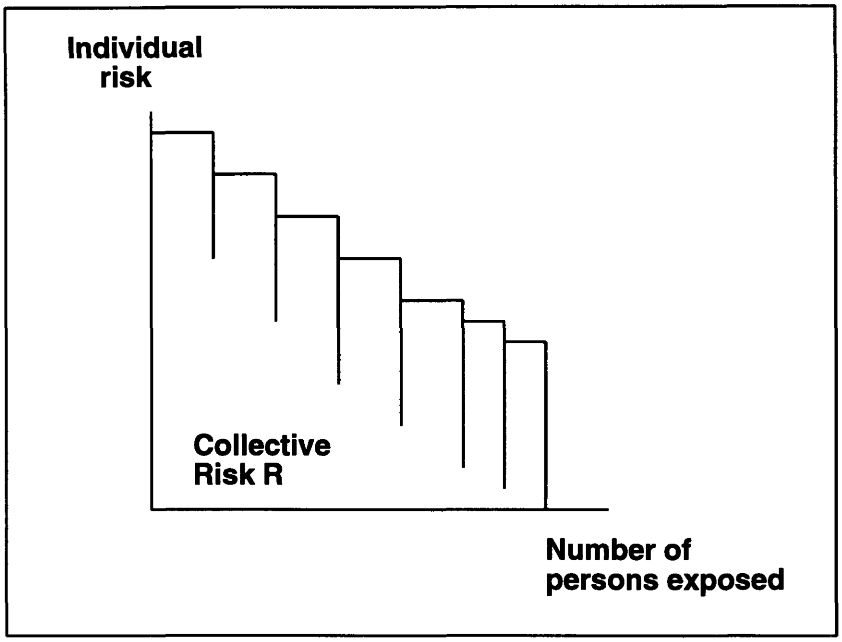


Figure 2-1: Definition of individual and collective risk

response depends upon how these ideas are expressed.

### 2.4.1 Risk as perceived by the public

The society perceives risk in a way that is sometimes not in accordance with what exactly happens in reality. This is the notion of perceived risk and is a very important concept that needs to be addressed in any study related to safety.

An example that immediately comes to mind is the way the public perceives the different types of transportation accidents. Automobile accidents result in approximately 120 deaths every day in the US. These accidents generally receive only a brief coverage in the local newspapers and receive no mention in the national newspapers. On the other hand, railroad and air travel are much safer than road travel, as shown in Figure 2-2 [17]. But, railroad or aviation accidents receive national coverage for a few weeks, as was shown by Sussman and Roth in their report on Amtrak's Sunset Limited crash in Alabama [20].

This leads us to the question of why some types of accidents are perceived more

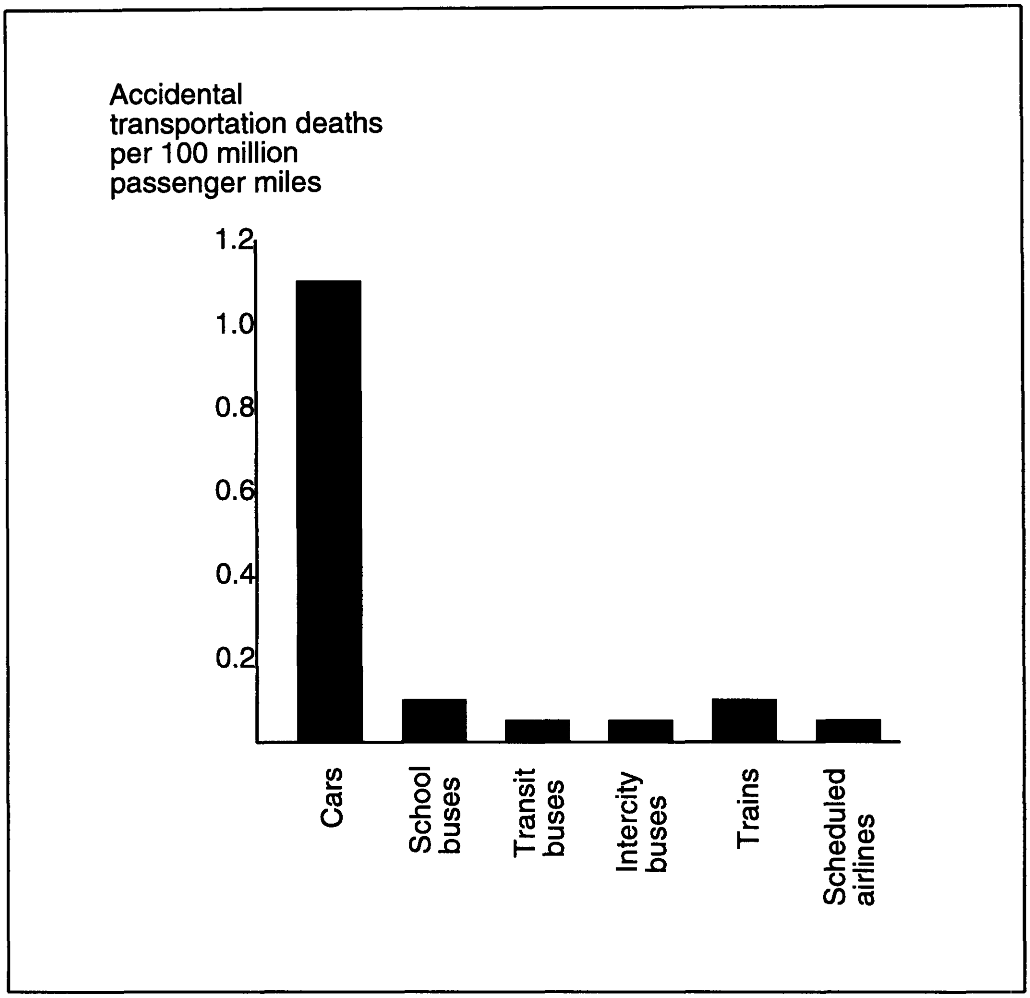


Figure 2-2: Comparison of the accidental deaths per 100 million passenger miles for different types of traffic

dangerous by the public and points to the following issues [17]:

- What are the factors which determine the way in which accidents are percieved by the public?
- How does society decide as to which risk is acceptable and which is unacceptable?

We would like to address both these questions in the forthcoming discussion.

The question of the factors influencing the perceptions of risk was addressed by Daniel

Litai [13] in the framework of the nuclear reactor safety study at MIT. The following is a summary of his methodology and results:

- Litai first determined the different attributes of risk. He defined an attribute as a 0-1 variable, with presence or absence of the attribute.
- Based on the attributes, he estimated the risks that humans are exposed to and determined the acceptable levels of these risks using the method of revealed preferences.
- He then compared the acceptable levels of two risks, which differ only by one attribute.
- The ratio of these acceptable levels gave the relative weights of the attributes in question.
- These ratios were called risk-conversion factors (RCF) and are presented in Table 2.1 [13].

| Pair of opposed attributes | Risk Conversion Factor |
|---|---|
| Natural vs. Man made | 1:20 |
| Ordinary vs. Catastrophic | 1:30 |
| Voluntary vs. Involuntary | 1:100 |
| Delayed vs. Immediate | 1:30 |
| Controllable vs. Uncontrollable | 1:5-10 |
| Old vs. New | 1:10 |
| Necessary vs. Luxury | 1:1 |
| Regular vs. Occasional | 1:1 |

Table 2.1: Risk Conversion Factors

In the present work, we are going to use these risk-conversion factors (RCF) to define the notion of perceived risk. We emphasize the fact that the risk-conversion factors (RCF) were developed in the context of nuclear reactor safety and could be different for transportation systems or in different societies.

Let us now address the second question and look at some of the factors which determine the acceptability of risk [17].

- Countries and societies which have high death rates from natural causes such as floods, earthquakes and epidemics are found to have high levels of "background risk." This is mainly found in third world countries where the level of acceptability of risk is high. This leads to such societies accepting higher risks in transportation as well. But affluent countries like Japan with high life expectancies (or low background risk) demand high safety standards in transportation.

- Catastrophic accidents, which have the potential for enormous consequences, are extremely feared and society wants to reduce such risks even at high cost.

- New technologies demand relatively less tolerance than existing technologies.

- A man-made system warrants lower acceptability level of risk by society since it is partly under the control of society, as opposed to natural hazards which are totally out of human control.

- Risks that have delayed effects are accepted more easily by society than those with immediate effects such as train accidents.

From the above discussion, it is evident that the answers to the two questions are quite inter-related. In fact, the risk-conversion factors (RCF) quantitatively establish the degree to which different attributes of risk are found acceptable or unacceptable by society.

This quantification is incorporated by extending the existing definition of risk to include the effect of the attributes on risk. This new term, called perceived risk $R_p$, is defined as

$$R_p = \sum_{i=1}^{n} p_i c_i \varphi(c_i) \tag{2.2}$$

where $\varphi(c_i)$ : set of perceived risk weights that assign a relative importance to the factors affecting the perceptions of risk

Another issue that is connected to the notion of perceived risk is the way in which information about safety is disseminated to the public. Such information must be conveyed in a way that it does not confuse the public because the public is heavily influenced by the way in which information is conveyed. This can best be illustrated by an example. Let us consider the following three different ways to convey information about the safety of air transportation in the US today [17].

1. "An individual boarding a domestic flight of one of the major airlines in the United States will be killed in an aviation accident with probability equal to 1 in 4,000,000".

2. "If an individual takes a domestic flight of one of the major airlines in the United States, the probability of he (or she) being killed in an accident is equal to half the probability of winning the Big Prize in the "MegaBucks" Lottery in the state of Massachusetts (One must choose correctly 6 out of a possible 36 numbers to win the lottery.)"

3. "If an individual takes a domestic flight on one of the major airlines in the United States, the average time until he (or she) dies in an accident is approximately 11,000 years".

The first statement does not depict the actual probability clearly since very few people can actually comprehend how small a probability 1 in 4,000,000 is. The second statement is misleading since many people play the "MegaBucks" Lottery every week and believe that they have a chance to win the prize. Someone does win the lottery every week, so this comparison of airline safety to the chances of winning the lottery can actually frighten people. The third statement is the most effective way of conveying information about the safety of air travel since people immediately know that air travel cannot significantly affect their life expectancies.

Let us now turn to the third component of the risk assessment study, namely, the optimal allocation of resources.

## 2.5 Optimal Allocation of Resources

In this section, we address the question of how best we can allocate the limited resources for safety such that we can achieve the maximum possible benefit. This is a very important question from the viewpoint of the company or agency investing in safety measures. Specifically, we talk about the extension of the existing definition of risk to include the monetary cost of an accident and further discuss the methodology by which an optimal decision can be made.

### 2.5.1 The Marginal Cost Criterion

Let us first look at the relationship between risk and cost as shown in Figure 2-3. This curve is constructed as follows:

1. We first identify all the safety measures that can be applied to the system of interest. We not only consider individual safety measures, but combinations of safety measures as well because they may be more effective than the sum of the individual measures taken together.

2. We then determine the cost and the benefit of each of the safety measures (and their possible combinations). The benefit of each safety measure (and their combinations) is measured as the reduction in the collective risk from the base value of risk (which is point A in Figure 2-3).

3. Each safety measure (and their combinations) is plotted as an individual point on a risk-cost diagram, the points representing the cost and the reduction in risk for that safety measure (and their combinations).

4. The optimal curve for risk reduction is drawn by connecting all the points which yield the largest reduction in risk for all possible values of the cost.This curve is analogous to the curve obtained when determining the optimal combination of factors of production for a firm in microeconomic theory. Thus, we call the curve as the efficiency frontier for risk reduction.

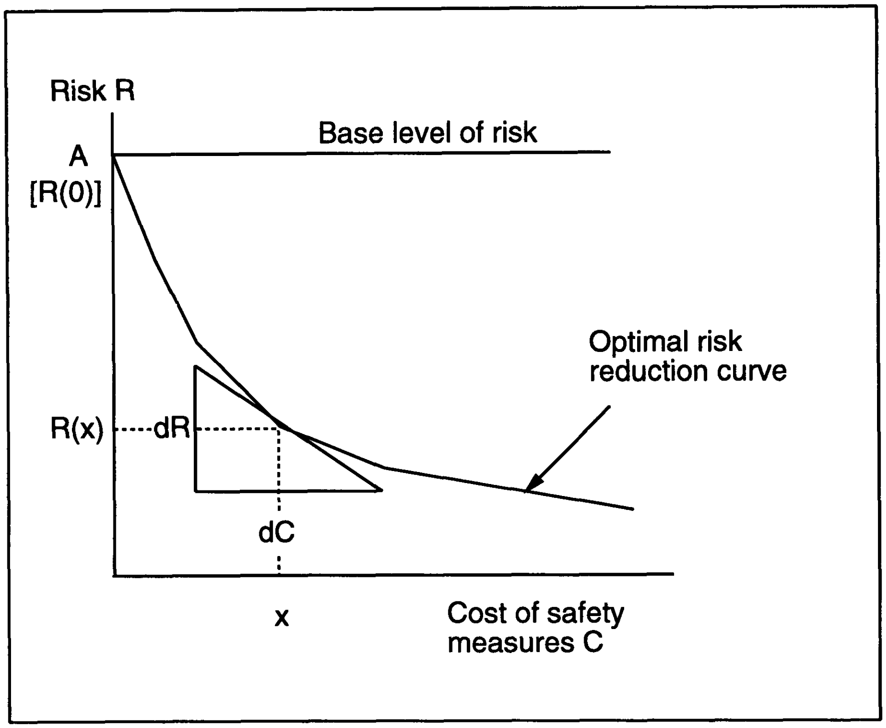


Figure 2-3: Optimal risk reduction investment

In theory, the risk reduction curve obeys diminishing marginal returns to scale. This implies that the incremental cost of reducing the risk by one unit keeps increasing as we go down the risk reduction curve. For the sake of argument, let us assume that the consequences of a hazardous activity is the loss of human lives. The inverse slope of the risk reduction curve is the incremental cost that is needed in order to reduce the risk by one unit i.e. it is the marginal cost of saving a life. This marginal cost can also be compared to the amount that one is willing to pay for a marginal increase in safety i.e. it is the willingness-to-pay to save a life.

The definition of perceived risk can now be extended to include the marginal cost criterion. The new definition, termed monetary collective risk $R_m$ [4], is given by

$$R_m = \sum_{i=1}^{n} p_i c_i \varphi(c_i) w_i \tag{2.3}$$

where $p_i$ : probability of occurrence of event i

$c_i$ : expected consequences of event i

$\varphi(c_i)$ : set of perceived risk weights that assign a relative importance to the factors affecting the perceptions of risk

$w_i$ : marginal cost or the willingness-to-pay to save a life

The advantages of including the marginal cost in the definition of risk are manifold [3]:

1. It makes the definition of risk more tractable and allows for the quantification of value judgments.
2. Though we have included fatalities as the only consequence, other consequences such as injuries, cost of damages etc can be conveniently added up to obtain the collective risk.

### 2.5.2 Optimal Investment Level

In the last section, we established the definition of the monetary collective risk. Let us now look at what is the optimal level of investment such that maximum benefit is achieved in terms of risk reduction.

Consider Figure 2-3 which shows the relation between the cost of safety measures (in \$) plotted on the $x$-axis and the monetary collective risk $R_m$ (in \$) on the $y$-axis. Let $x$ denote the cost of some safety measure and $R_x$ the monetary collective risk corresponding to that safety measure.

The benefit obtained from investment $x$ is given by

$$B_x = [R_0 - R_x] - x \tag{2.4}$$

Our goal is to maximize this benefit.

$$\max_x B_x = [R_0 - R_x] - x \tag{2.5}$$

A necessary condition for x to be the optimal investment is

$$\frac{dB_x}{dx} = 0 \tag{2.6}$$

$$\Rightarrow R'_{x^\star} = -1 \tag{2.7}$$

i.e. the marginal risk reduction per unit of investment is equal to -1.

This is the condition for the optimal investment level.

# Chapter 3

# Exploratory Analysis of the Level Crossing Accidents

## 3.1 Introduction

JR East is the largest of the six private railroads in Japan, formed after the Japan National Railways (JNR) was privatized in 1987. It is the largest provider of public transportation in the busiest part of Japan. JR East provides services to approximately 60 million people in metropolitan Tokyo and the 16 prefectures of eastern Japan. A total workforce of around 80,000 provides service to 16.66 million passengers every day. An average of 12,000 trains run on the network of 7,502 kilometers every day. The statistics of JR East are shown in Table 3.1.

A railway network as large and complex as JR East is bound to be exposed to risks. The company has recognized this and made safety its top priority. A total of 400 billion yen was invested in the five year period from 1989 to 1993 to achieve the goal of "Zero Passenger Fatalities" [1]. Some of the investment was on installing the Automatic Train Stop-Pattern (ATS-P) and upgrading level crossings by installing barriers and obstacle detectors. If we look at the number of passenger fatalities per passenger-km of service, JR East has had 13 passenger fatalities in 676 billion passenger-km of service, or one fatality for every 52 billion passenger-km of service [19]. This measure suggests that JR East is about 40 times safer than the German, English, French and

| | |
|---|---|
| Number of employees | 80,860 |
| Passenger line network | 7,502 km |
| Number of stations | 1,708 |
| Passengers (annual) | 6.08 billion |
| Average trains per day | 12,119 |
| Average train-km per day | 711,000 |
| Average passengers per day | 16.66 million |
| Rolling stock | 14,046 cars |
| Electrification | 5,457 km (72%) |
| Operating revenues | 1,974 billion yen |

Table 3.1: JR East statistics

US railroads [19].

The JR East network of 7,502 kilometers had a total of 927 level crossing accidents in the six years from 1987 to 1992[1]. The number of accidents declined every year during this period. 247 accidents occurred at crossings in 1987, and reduced to 86 in 1993. Though none of the accidents resulted in major consequences for train passengers and people on the road, a potential for catastrophic accidents does exist and will be discussed in Section 3.8. In fact, some of the derailment accidents that have occurred on the network have been at level crossings. These accidents can lead to catastrophic consequences if the accident occurs in a crowded area during the peak period. The potential for catastrophic accidents, thus, cannot be completely ruled out.

The most serious accident on the JR East network occurred in December, 1988 when two trains collided at Higashinakano station. The driver of the train changed the Automatic Train Stop (ATS) to manual override, though it was indicating the red light implying that another train was in the vicinity. He did apply the brakes, but there was not enough time to stop and the two trains collided at the station. This accident resulted in 1 passenger fatality and 116 passenger injuries. This collision led to the establishment of the Safety Research Laboratory in April, 1989. This laboratory carries out research in the areas of train separation control, accidents at level

[1] Here, the year refers to the Japanese year. Thus, the six year data is from April, 1987 to March, 1993.

crossings, accidents due to natural hazards, human factors in railroad and the like.

## 3.2 The Level Crossing and Accident Databases

The Safety Research Laboratory of JR East maintains two databases to characterize the level crossings on their network: The Level Crossing Database [10] and the Accident Database [9]. The Level Crossing Database contains the characteristics of all the level crossings on the JR East railway network. As of September 1994, there were a total of 7894 level crossings. The Level Crossing Database is extremely detailed in its description of the crossings and has 92 attributes for each of the crossings. The Level Crossing Database is given in Appendix 1 of the thesis.
The Accident Database gives the characteristics of the accidents that have occurred since April, 1987 on these level crossings. A total of 927 accidents occurred from April, 1987 to March, 1993. Like the Level Crossing Database, the Accident Database is detailed in its description of the accidents and has 57 attributes for each of the accidents. The Accident Database is given in Appendix 2 of the thesis.
Let us now examine in detail the attributes of the Level Crossing Database and the Accident Database.

### 3.2.1 The Level Crossing Database

The Level Crossing Database gives a detailed description of each of the level crossings on the network. As of September 1994, there were a total of 7894 crossings. The number of crossings decreased every year from 1987 to 1994. This is mainly due to three factors:

- Crossings were eliminated by constructing overbridges or underpasses.
- Crossings were combined.
- The management of the line changed from JR East to some other company.

Each level crossing has 92 attributes associated with it. These attributes encompass the entire gamut of the various characteristics of the crossing. Let us now go through some of the definitions of the level crossing attributes:

- Track grade: There are four types of track grade:

  1. Grade 1: Tracks that carry more than 20,000,000 tons/year.
  2. Grade 2: Tracks that carry more than 10,000,000 tons/year but less than 20,000,000 tons/year.
  3. Grade 3: Tracks that carry more than 5,000,000 tons/year but less than 10,000,000 tons/year.
  4. Grade 4: Tracks that carry less than 5,000,000 tons/year.

- Level crossing grade: This refers to the type of safety measure present at the crossing. They fall into three categories:

  1. Grade 1 crossing: This crossing is equipped with a warning system and a barrier. The warning system consists of a warning bell and flasher. Normally, there are two barriers on each side of the crossing. These barriers are similar to the four quadrant gates found in the US. Figure 3-1 shows how the safety devices at a typical Grade 1 level crossing function. Figure 4-1 shows the schematic diagram of a typical Grade 1 crossing.
  2. Grade 3 crossing: This crossing is equipped only with a warning system. There are around 300 Grade 3 crossings on the JR East network.
  3. Grade 4 crossing: This crossing has only a level crossing sign. It is neither equipped with a warning system nor a barrier.

- Gate mechanism: The barriers present at Grade 1 crossings can be operated in three ways:

  1. Automatic barrier: As the name suggests, this barrier is operated automatically. It is connected to the train detection system. When the detection system detects the approaching train, the barrier starts coming down and is down before the train reaches the crossing.

2. Semiautomatic-automatic barrier: This type of barrier is installed in the station area so that it can be operated manually as well as automatically. The manual operation is usually done by the maintenance staff under the supervision of the station master.

3. Non-automatic barrier: This barrier is present at crossings which are located in urban areas and have a high volume of road traffic. They are manually operated by three or four railroad people who ensure that all the road traffic is cleared before the train reaches the crossing. At present, there are no manual crossings on the JR East network.

- Alarm button: This is normally present on either side of the crossing. It is placed in a convenient position so that it can be easily accessed in the event of an emergency, and ensuring that it is out of the reach of children. It is connected to the railroad signalling system and if activated, turns the signal red.

- Obstacle detector: This safety device can detect the presence of any road vehicles stuck on the level crossing. Normally, 6 detectors are present at a single track crossing. Figure 3-2 shows the position of the detectors at a single track crossing. The S's are the sources of the laser beam and the R's are the receivers. Any vehicle caught in the crossing breaks the path of the laser beam and activates the railroad signalling system connected to the detector. A vehicle should be in the path of the beam for 6 sec continuously to activate the signal. The detector is activated from the moment the warning bell starts ringing at the crossing.

- Direction indicator: This device is connected to the train detection system and indicates the direction from which the train is approaching the level crossing.

- Overhanging warning device: Some crossings have very low visibility on the order of a few meters. At these crossings, the warning device is installed above the road instead of by the side so that it can be easily seen by a vehicle approaching the crossing.

- Rail traffic volume: This is the number of trains going across the level crossing everyday.

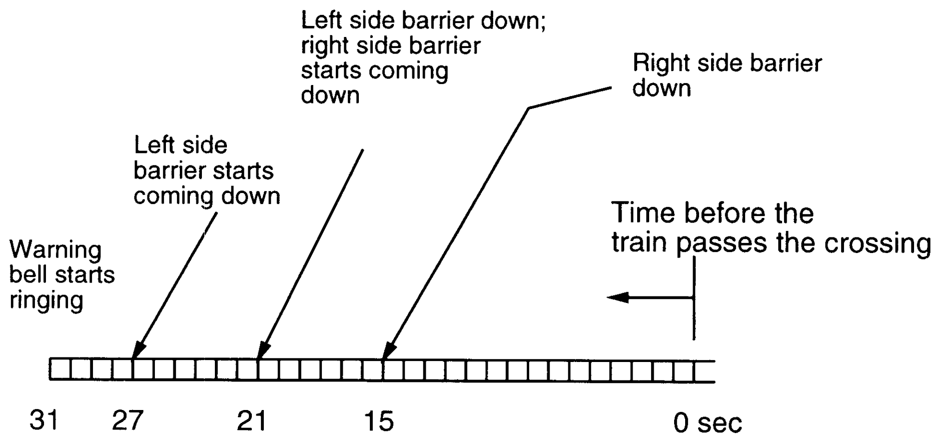


Figure 3-1: Operation of a Grade 1 level crossing

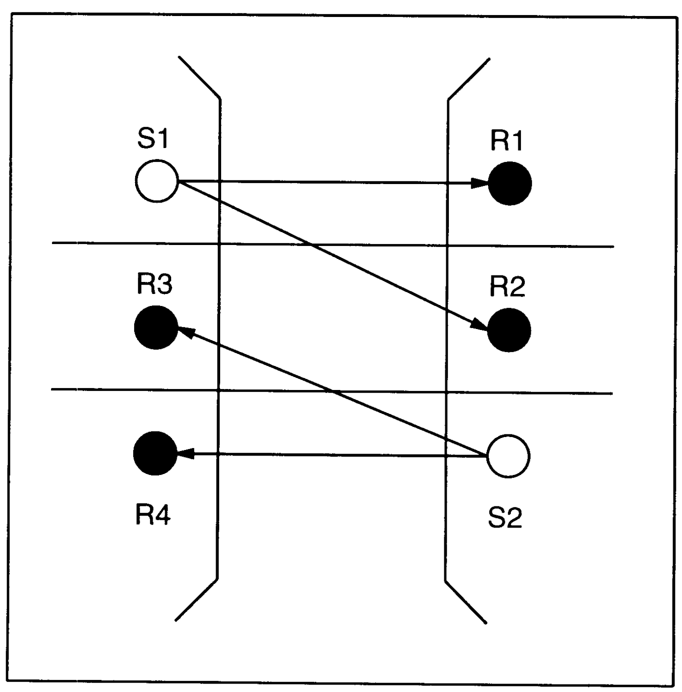


Figure 3-2: Placement of obstacle detectors at a level crossing

### 3.2.2 The Accident Database

The Accident Database gives a detailed description of the level crossing accidents. The accidents in this database are recorded from April, 1987 to date. Let us define some of the attributes of this database:

- Accident cause: JR East defines nine causes of accidents at level crossings. They are explained below:

  1. Intrusion against the level crossing gate: This accident occurs when the level crossing barrier is down and a road vehicle intrudes against this barrier and goes into the crossing area. This accident can occur only at a Grade 1 crossing (crossing equipped with a warning system and barrier.)

  2. Ignorance of warning: At a Grade 1 crossing, this accident occurs during the time between the ringing of the warning bell and the descent of the level crossing barrier when the road vehicle ignores the bell and goes into the crossing area but is not able to get out on the other side. This may happen due to many reasons:

     - The driver may panic resulting in the vehicle stopping in the middle of the crossing.
     - The driver might veer to the side of the road and get caught on the crossing.
     - The vehicle's engine might stop resulting in it being caught on the crossing.

     At a Grade 3 crossing, this accident occurs from the moment the warning bell starts ringing (there is no barrier at a Grade 3 crossing) and similar circumstances result as explained for the case of the Grade 1 crossing.

  3. Impossible traversing: This accident occurs only at a Grade 4 crossing when the vehicle ignores the presence of the level crossing sign and tries to go across the crossing.

4. Side hit: This accident is caused when the train is already at the crossing and the vehicle goes into the crossing, either because the driver did not perceive the presence of the crossing or he was intoxicated or was overspeeding and did not have enough time to stop.

5. Clearance invasion: This accident occurs when the vehicle does not give enough room for the train to get past the crossing - either the vehicle is stopped beyond the stop line and too close to the tracks or it has something projecting from it.

6. Wheek wreck: This accident occurs when the wheels of the vehicle are stuck on the track as the vehicle has veered to the side of the crossing (the difference in height is about 15 cm.)

7. Engine stalling: The engine of the vehicle stops as it is going across the crossing.

8. Traffic congestion: This accident normally occurs when the crossing is close to a road intersection. The vehicle enters the crossing but is not able to get out because there are vehicles stopped in front of it at the road intersection.

9. Device trouble: This accident occurs when one of the level crossing safety devices do not work, thus allowing the unaware vehicle to go into the crossing though a train is approaching the crossing. For JR East, this is a very serious type of level crossing accident because it falls under their responsibility. Accidents caused by device trouble may be due to four factors:

   - Mistake on wiring: A wiring mistake may result due to inappropriateness between the blueprint and the actual wiring carried out.
   - Mistake on maintanance: Mistake by a railroad employee during maintenance.
   - Poor condition of short circuit: This occurs when there is a problem with the circulation of current due to rust of the rails.

- Poor condition of treatment: This occurs at crossings equipped with semiautomatic-automatic barriers. These barriers are seldom operated manually, so the maintenance crew sometimes forget to operate the safety devices of the crossing. Accidents resulting due to these mistakes are termed "poor condition of treatment."

## 3.3 Exploratory analysis of the Level Crossing Database

As mentioned earlier, the level crossing database lists the characteristics of the 7894 crossings on the JR East system. We will now conduct an exploratory analysis of the level crossing database.

### 3.3.1 Grade of the crossing

Table 3.2 shows the number and percentage of crossings of each grade. 85% of the crossings are Grade 1 crossings. They are present throughout the JR East network. 4.7% of the crossings are Grade 3 crossings. These crossings are being eliminated by converting them to Grade 1 crossings. 10.3% of the crossings are Grade 4 crossings. These crossings are mainly located in rural areas and are predominantly single-track crossings.

| Grade of the crossing | Number of crossings | Percentage of crossings |
|---|---|---|
| Grade 1 | 6722 | 85% |
| Grade 3 | 372 | 4.7% |
| Grade 4 | 800 | 10.3% |

Table 3.2: Level crossing grade

### 3.3.2 Number of crossing tracks

Table 3.3 shows the number and percentage of crossings of each grade having single track, two tracks, three tracks, four tracks and five or more tracks.

| | Grade 1 | | Grade 3 | | Grade 4 | |
|---|---|---|---|---|---|---|
| No. of tracks | No. of crs. | % of crs. | No. of crs. | % of crs. | No. of crs. | % of crs. |
| Single | 4215 | 80.6 | 293 | 5.6 | 719 | 13.8 |
| Double | 2282 | 93.8 | 75 | 3.1 | 75 | 3.1 |
| Triple | 89 | 96.7 | 1 | 1.1 | 2 | 2.2 |
| Quadruple | 78 | 98.7 | 1 | 1.3 | 0 | - |
| Five or more | 58 | 90.6 | 2 | 3.1 | 4 | 6.3 |

Table 3.3: Crossings by number of tracks

### 3.3.3 Visibility on the left and right

Figure 3-3 shows the visibility of the level crossing from the left and right side of the road leading to the crossing. They indicate that the visibilities are approximately log-normally distributed. 1645 crossings have less than 20 m visibility.

### 3.3.4 Road gradient

Table 3.4 shows the crossings grouped on the basis of the gradient of the road leading to the crossing.

| Road gradient | Number of crossings |
|---|---|
| Level | 1759 |
| Upward | 3577 |
| Downward | 2553 |
| With steps | 5 |

Table 3.4: Crossings by road gradient

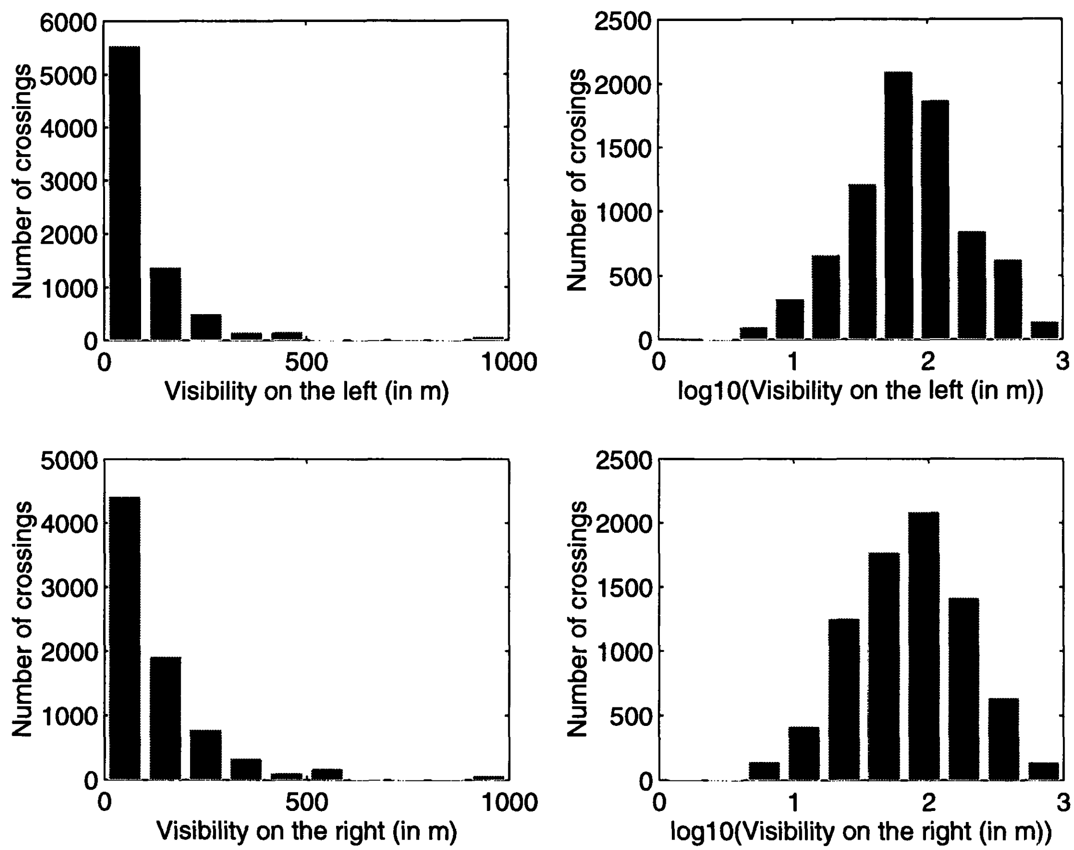


Figure 3-3: Visibility on the left and right of the crossing

### 3.3.5 Distance of the crossing to the nearest intersection

Figure 3-4 shows the distance of the various crossings from the nearest road intersection. The top figure shows the distance of all crossings, whereas the bottom figure shows the distance of only the Grade 1 crossings from the nearest intersection. The mean distance of all the crossings is just 3.81 m and the mean distance of the Grade 1 crossings is 4.14 m, both of which are less than the average length of a single car (which is about 5 m long). This has implications for accidents caused due to traffic congestion and is discussed in Section 3.6.5.

### 3.3.6 Location of the crossing

Table 3.5 shows the percentage of crossings located in industrial, commercial, residential and rural areas. 94% of the crossings are located either in residential or rural areas.

| Location | % of crossings |
|---|---|
| Rural | 61.8 |
| Residential | 32.0 |
| Commercial | 3.3 |
| Industrial | 2.7 |
| Port | 0.1 |

Table 3.5: Crossings by location of the crossing

### 3.3.7 Obstacle detector

Table 3.6 shows the number of crossings equipped with an obstacle detector.

### 3.3.8 Rail traffic volume

Figure 3-5 shows the variation in the rail traffic volume at all crossings, at Grade 1 crossings, at Grade 3 crossings and Grade 4 crossings. The mean number of trains going across the crossing per day is also indicated.

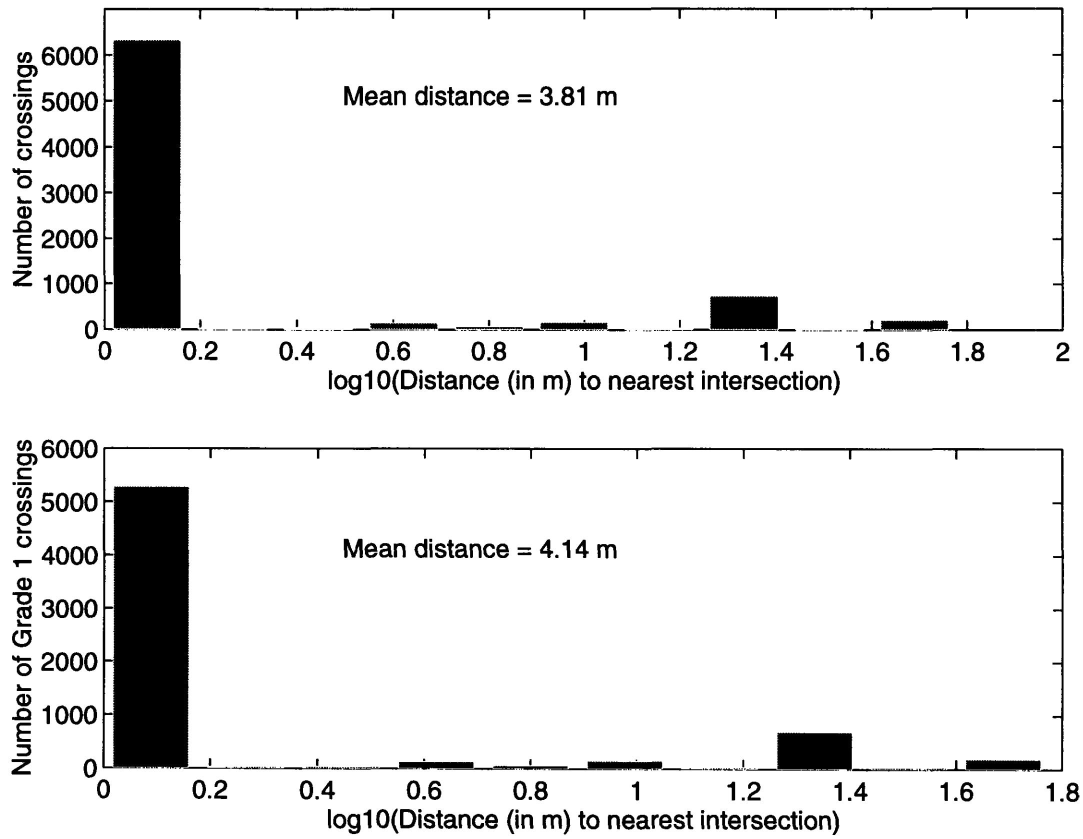


Figure 3-4: Crossing distance (in m) from the nearest road intersection

| Presence/absence of detector | Number of crossings |
|---|---|
| None | 6913 |
| With detector | 981 |

Table 3.6: Crossings by the presence or absence of an obstacle detector

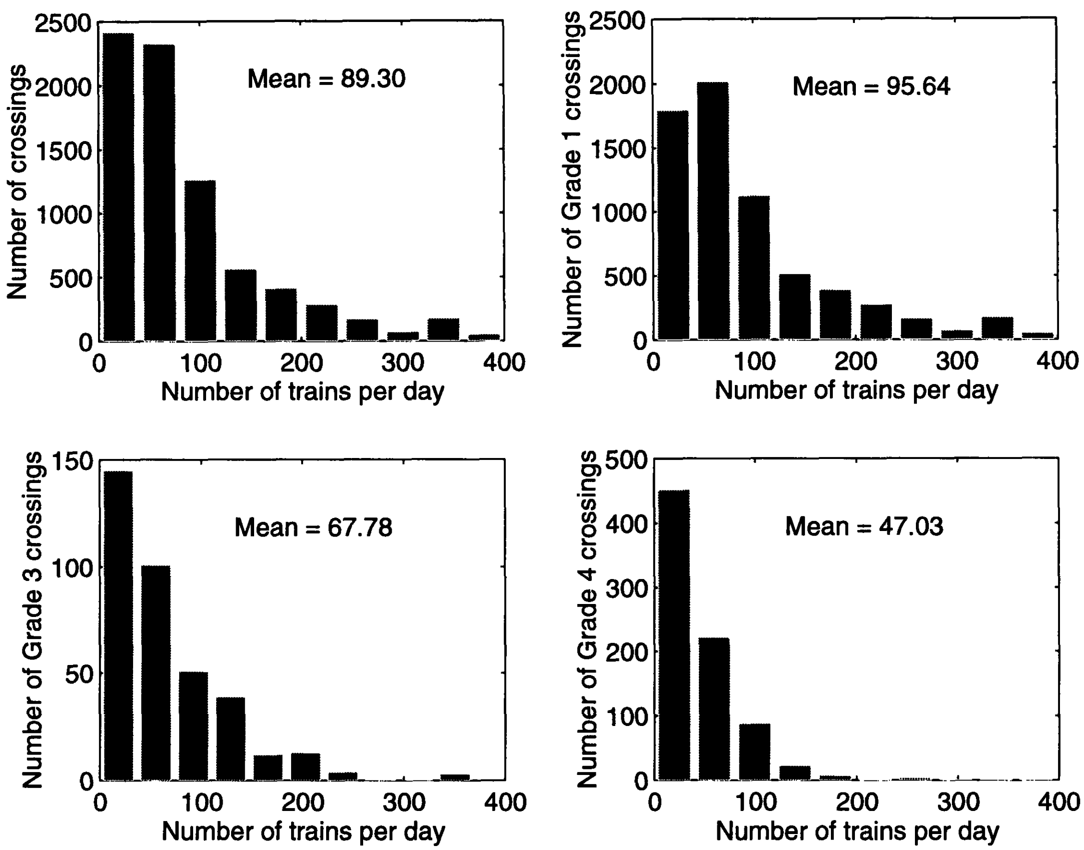


Figure 3-5: Rail traffic volume across all crossings

### 3.3.9 Automobile traffic volume

Figure 3-6 shows the variation in the automobile traffic volume across crossings. Most of the automobiles go across Grade 1 crossings (mean number of automobiles is 732.73.) Very few automobiles go through Grade 3 and Grade 4 crossings.

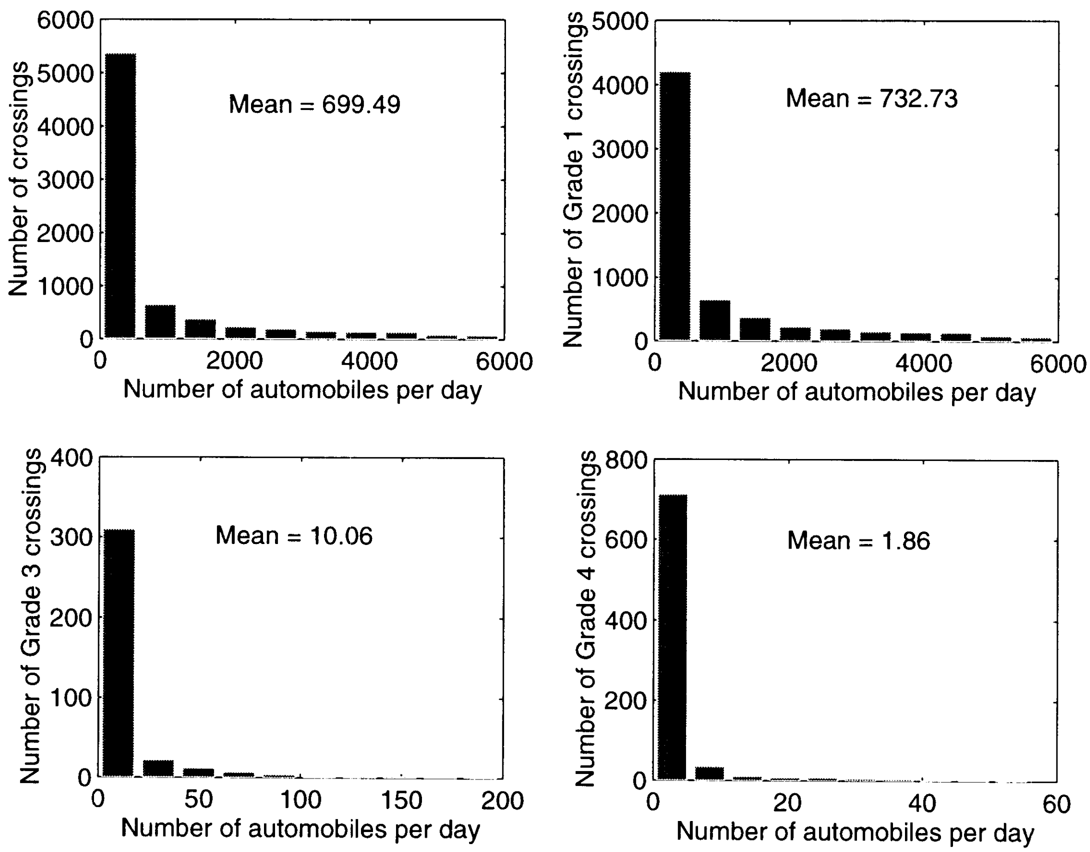


Figure 3-6: Variation of the automobile traffic volume across all crossings

### 3.3.10 Freight truck traffic volume

Figure 3-7 shows the variation in the freight truck traffic across crossings. The mean number of freight trucks per day (=19.04) is much lower than the number of automobiles per day (=617.90). Very few freight trucks go through Grade 3 and Grade 4 crossings.

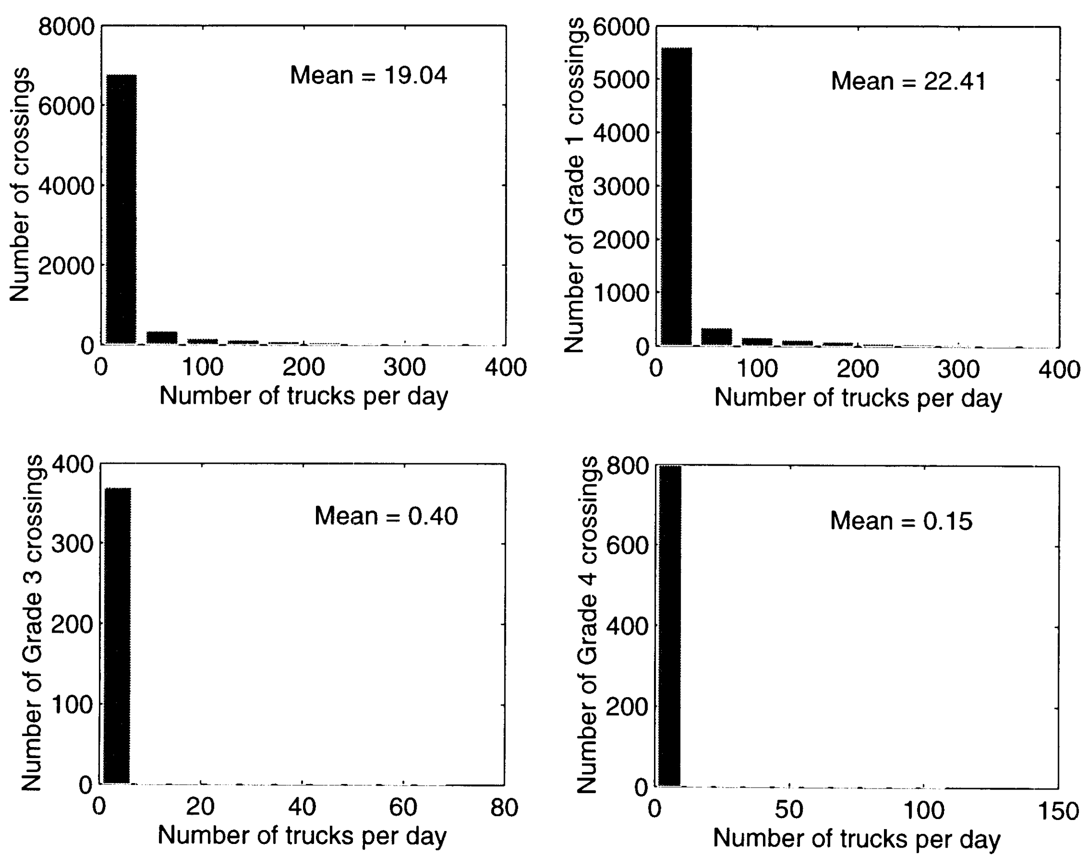


Figure 3-7: Freight truck traffic across crossings

### 3.3.11 Motorcycle traffic volume

Figure 3-8 shows the variation in the motorcycle traffic across all crossings. The mean number of motorcycles per day is 71.31 and the means are very low at Grade 3 and Grade 4 crossings.

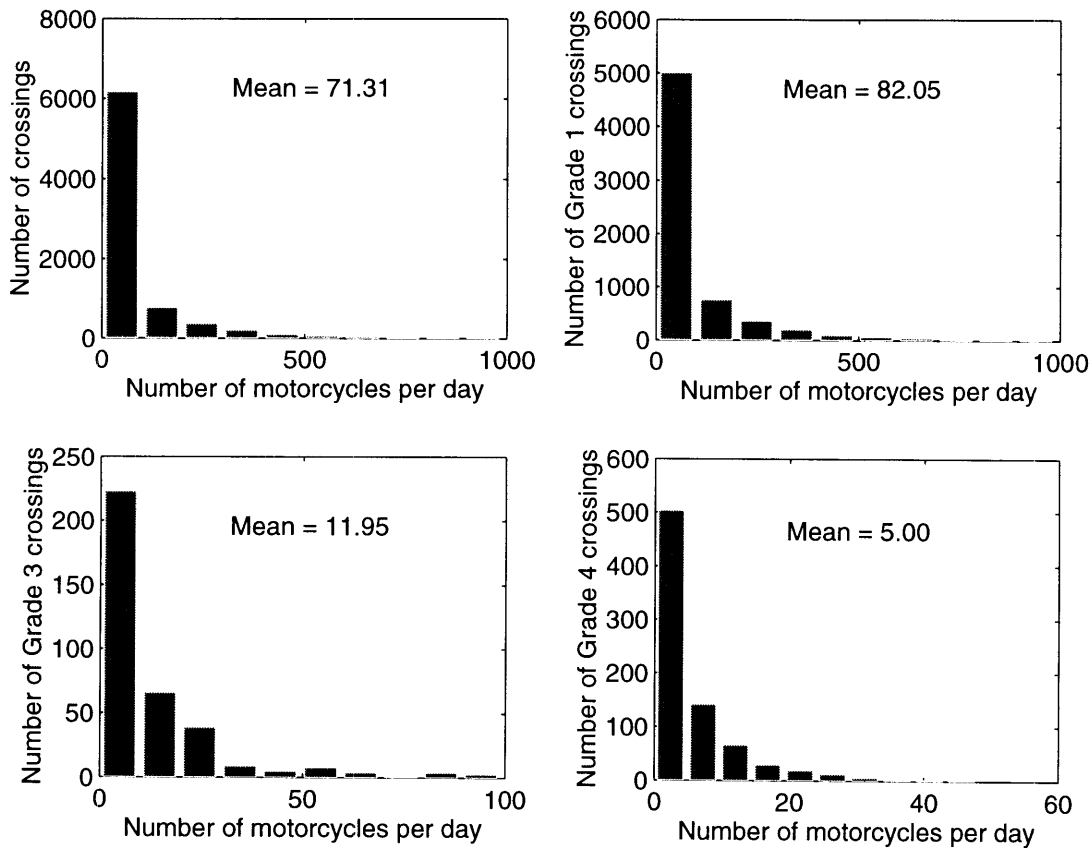


Figure 3-8: Motorcycle traffic volume across all crossings

### 3.3.12 Number of pedestrians going across the crosing

Figure 3-9 shows the number of pedestrians going across the crossings. The mean number going through all crossings is 215.00.

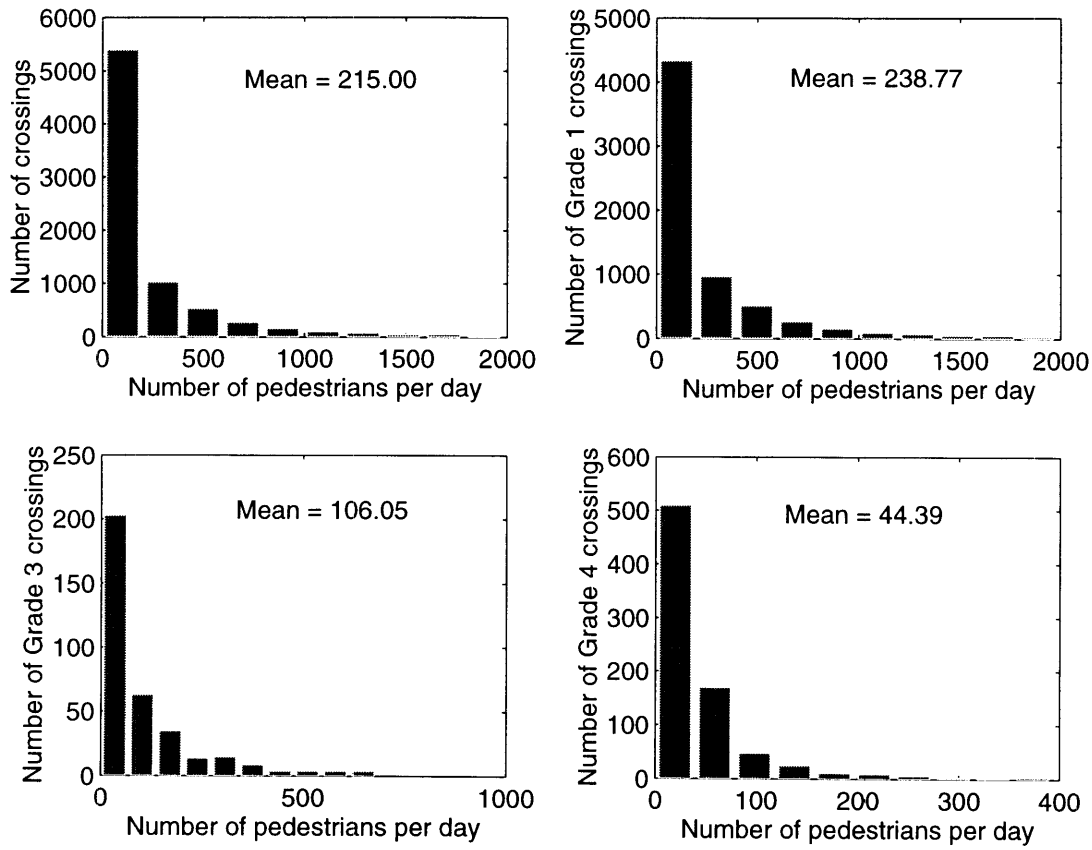


Figure 3-9: Pedestrians going across all crossings

### 3.3.13 Light vehicles going across all crossings

Figure 3-10 shows the number of light vehicles going across all crossings. These vehicles include bicycles and small vehicles like scooters. The mean number of these vehicles going through all crossings is 183.51.

## 3.4 Exploratory analysis of the Accident Database

A total of 927 accidents have occurred from April, 1987 to March, 1993. Let us now explore the accident database.

### 3.4.1 Number of accidents with time

Figure 3-11 shows the variation of the number of accidents since the inception of JR East in 1987. The number of accidents has been steadily declining indicating the success of the JR East investment in safety. Most of the decline has been in the earlier years and a relatively smaller decline has occurred in later years.

### 3.4.2 Number of accidents versus weather

Table 3.7 shows the number of accidents that have occurred at crossings having different weather conditions. These numbers have not been normalized, so the precise effect of the weather on the accident rate cannot be determined.

| Weather | No. of accidents | % of accidents |
|---|---|---|
| Sunny | 556 | 59.98 |
| Cloudy | 233 | 25.13 |
| Rainy | 97 | 10.46 |
| Snowy | 37 | 3.99 |
| Snow stormy | 4 | 0.43 |

Table 3.7: Accidents with the weather at the crossing

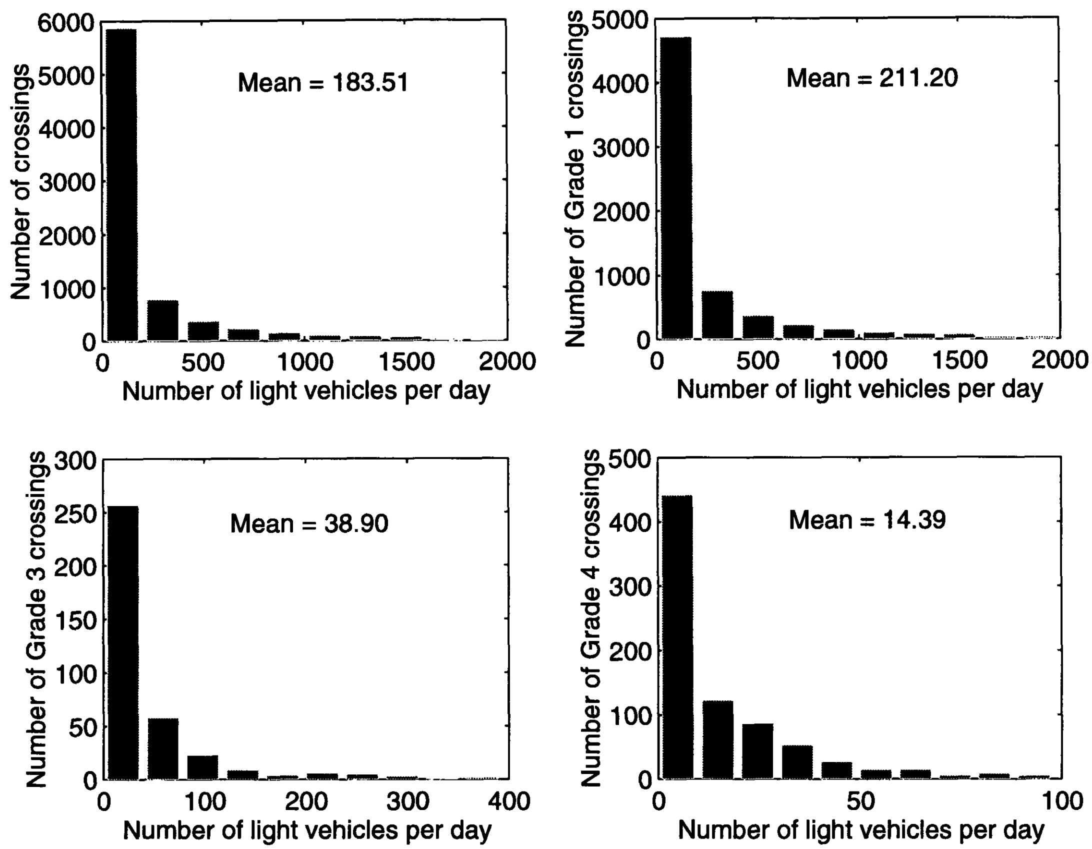


Figure 3-10: Light vehicle traffic across all crossings

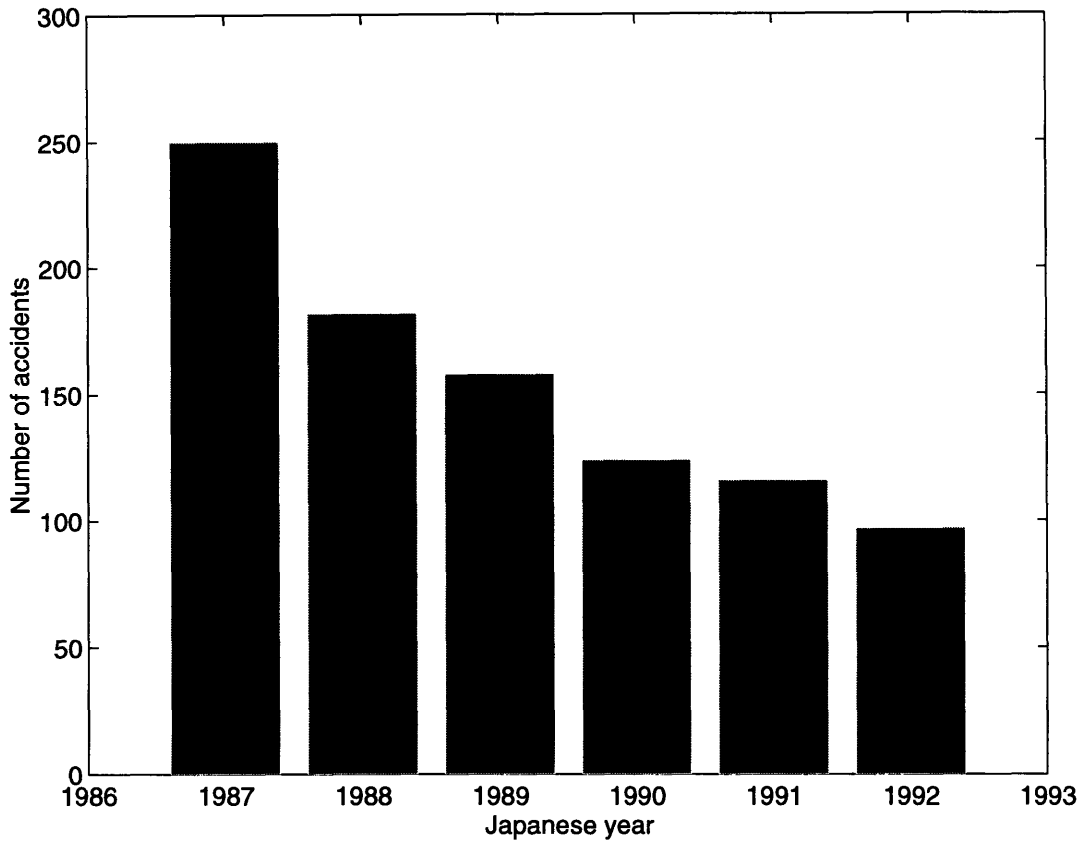


Figure 3-11: Variation of the accidents with time

### 3.4.3 Injuries in the accidents

Level crossing accidents have resulted in few injuries to passengers. 10 accidents injured passengers on board and 3 injured passengers not on board. As shown in Figure 3-12), a majority of the accidents did not lead to any injuries. 741 accidents resulted in no injuries to third party persons[2], 163 led to 1 injury and 16 led to 2 injuries. 1 accident resulted in more than 9 injuries to third party persons. 733 accidents resulted in no injuries, 160 led to 1 injury and 18 led to 2 injuries.

### 3.4.4 Fatalities in the accidents

Level crossing accidents have not resulted in any passenger fatalities. Any fatalities, if resulted, have been third party fatalities. 722 accidents have not resulted in any third party fatality, 197 accidents led to 1 fatality and 8 accidents have resulted in 2 fatalities at the crossing (Figure 3-13).

### 3.4.5 Train delays as a result of the accidents

Accidents have not resulted in significant train delays. Mean delays of the order of around 30-45 min have resulted from these accidents (Figure 3-14).

### 3.4.6 Train cancellations

The number of cancelled trains in the accidents has been much smaller than the number of trains delayed. The mean accident has resulted in around 20 train cancellations, though one or two accidents have resulted in more than 100 trains being cancelled (Figure 3-15).

[2]Third party persons refers to the people in automobiles and freight trucks, motorcyclists, bicyclists and pedestrians who are at the vicinity of the crossing on the road.

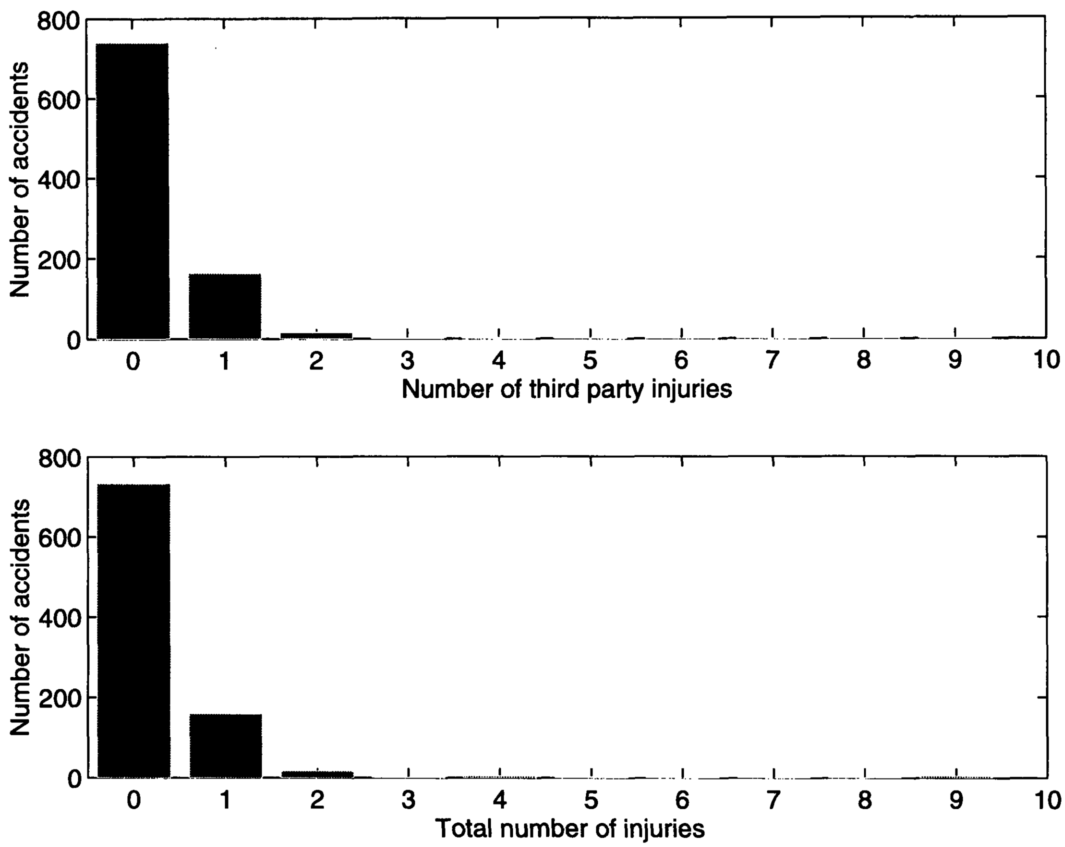


Figure 3-12: Number of third party and total injuries in all accidents

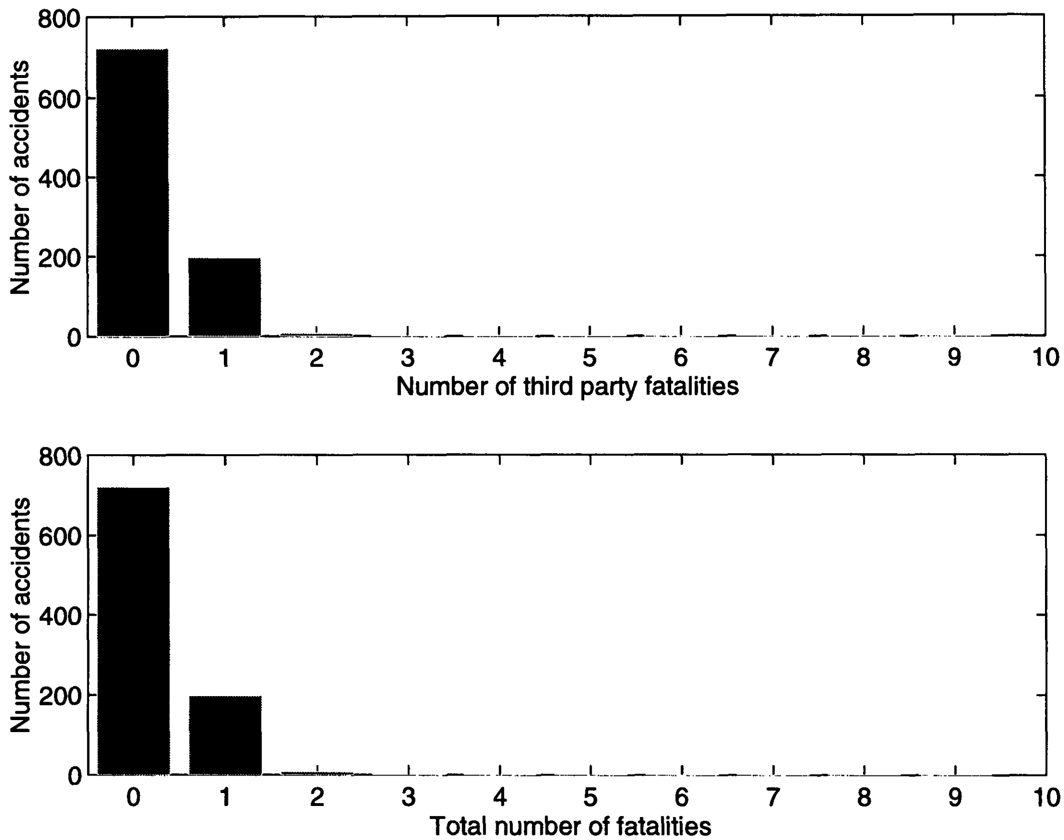


Figure 3-13: Number of third party and total fatalities in all accidents

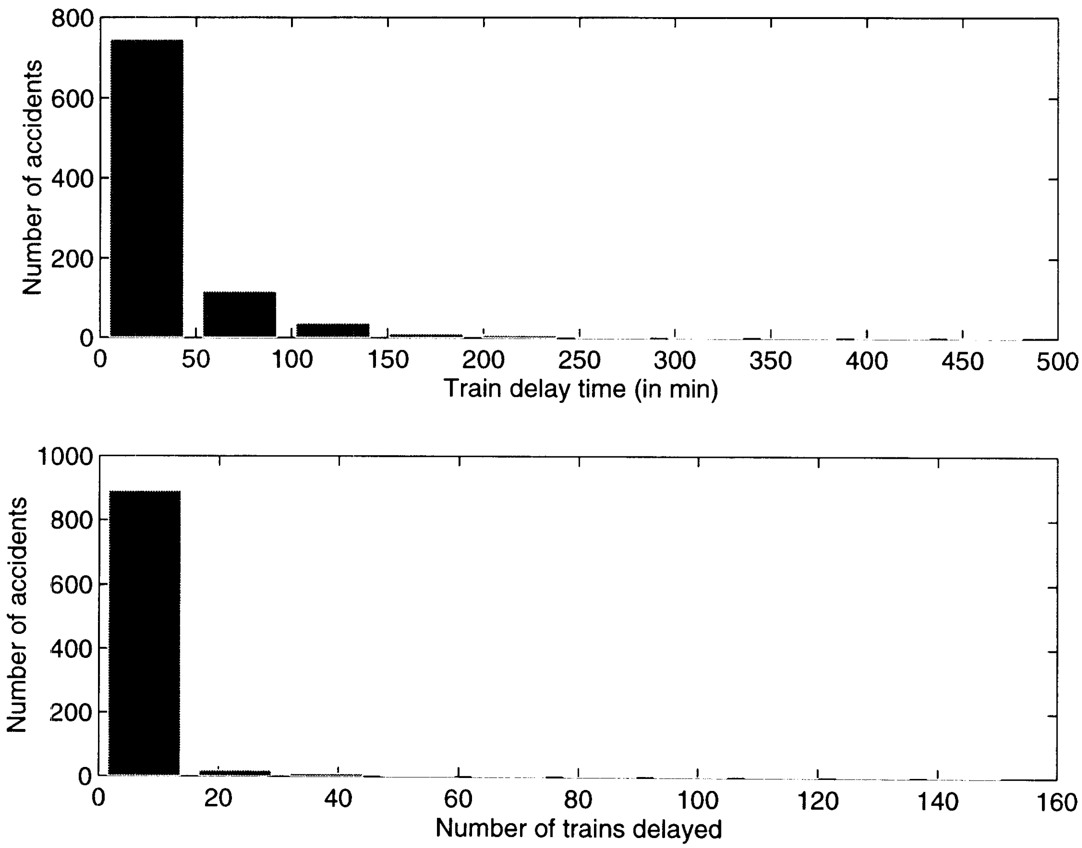


Figure 3-14: Delay time and number of trains delayed in all the accidents

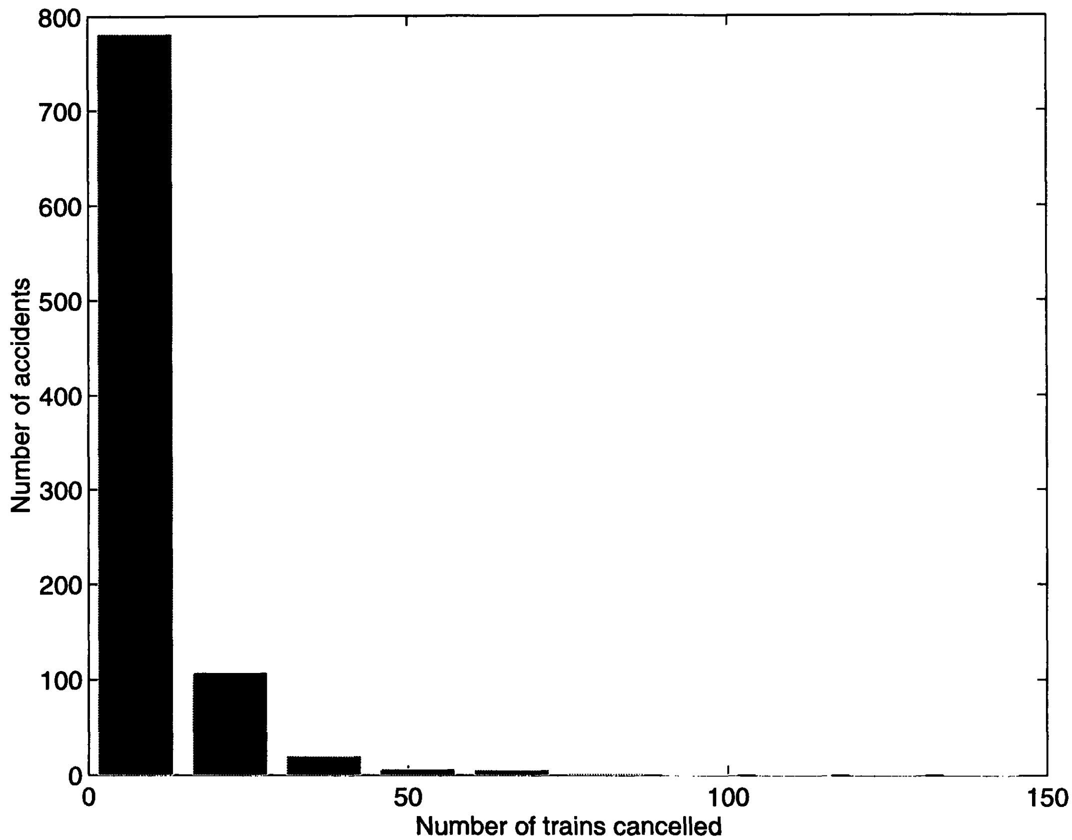


Figure 3-15: Cancelled trains in all accidents

### 3.4.7 Number of accidents by type of traffic involved

Table 3.8 shows the number of accidents that have occurred with respect to the type of traffic involved in the concerned accident. Automobiles account for almost half of the level crossing accidents (45.63%).

| Traffic type | No. of accidents | % of accidents |
|---|---|---|
| Passenger automobile | 423 | 45.63 |
| Freight truck | 146 | 15.75 |
| Pedestrian | 130 | 14.02 |
| Light vehicle | 88 | 9.49 |
| Motorcycle | 70 | 7.55 |
| Farming automobile | 17 | 1.83 |
| Large sized freight truck | 16 | 1.73 |
| Dump truck | 7 | 0.76 |
| Bus | 6 | 0.65 |
| Special automobile | 6 | 0.65 |
| Tricycle automobile | - | - |

Table 3.8: Accidents by type of traffic involved

### 3.4.8 Accident causes

The exact definition of the various causes of accidents at level crossings was given in Section 3.2.2.

#### Causes at all crossings

Table 3.9 gives the number and percentage of accidents by cause[3]. Intrusion against the level crossing gate and ignorance of warning account for 53% of the accidents.

#### Causes by grade of the crossing

Table 3.10 shows the split of the accidents that have occurred at different crossing grades by cause of the accident.

[3]Some of the accidents caused due to impossible traversing have been accounted under Grade 1 crossings, though they should only be for Grade 4 crossings.

| Accident cause | No. of accidents | % of accidents |
|---|---|---|
| Intrusion against LC gate | 145 | 15.64 |
| Ignorance of warning | 196 | 21.14 |
| Impossible traversing | 151 | 16.29 |
| Side hit | 36 | 3.88 |
| Clearance invasion | 77 | 8.31 |
| Wheel wreck | 93 | 10.03 |
| Engine stalling | 93 | 10.03 |
| Traffic congestion | 67 | 7.23 |
| Device trouble | - | - |
| Others | 69 | 7.44 |

Table 3.9: Accidents by cause

| Accident cause | Total acc. | Grade 1 | Grade 3 | Grade 4 |
|---|---|---|---|---|
| Intrusion against LC gate | 145 | 145 | 0 | 0 |
| Ignorance of warning | 196 | 143 | 43 | 0 |
| Side hit | 36 | 34 | 1 | 1 |
| Clearance invasion | 77 | 68 | 3 | 6 |
| Wheel wreck | 93 | 83 | 8 | 2 |
| Engine stalling | 93 | 91 | 0 | 2 |
| Traffic congestion | 67 | 67 | 0 | 0 |
| Device trouble | 0 | 0 | 0 | 0 |
| Others | 69 | 66 | 2 | 1 |

Table 3.10: Accidents by grade of accident for different causes

### Sub-causes for the accidents

In this section, sub-causes of some of the accident causes are explored and the relative contribution of these sub-causes to the occurrence of a level crossing accident is determined. The causality trees for the level crossing accidents are constructed as follows:

1. The primary or system failure is the accident which occurs at the level crossing.
2. The events leading to this accident are the various causes of level crossing accidents. Seven causes of accidents are considered: intrusion against the level crossing gate, ignorance of warning, side hit, clearance invasion, wheel wreck, engine stalling and traffic congestion.
3. Sub-trees are constructed for some of the accident causes.

The causality trees are constructed for automobile accidents, and the information about the accidents has been obtained from the Safety Research Laboratory of JR East.

Figure 3-16 shows the break up by seven different causes of automobile accidents at the crossings. 33% of the accidents have occurred when the automobile has ignored the level crossing warning and gone into the crossing, but has been unable to come out on the other side. 10% of the accidents have occurred due to intrusion against the level crossing gate. This is less than the percentage of accidents due to ignorance of warning, and is supported based on observations of two crossings on the JR East network. 45% of the accidents have occurred when the automobile is caught after legally entering the crossing. Though the obstacle detector has reduced the number of accidents caused due to wheel wreck, engine stalling and traffic congestion, they are an issue of concern in urban areas where crossings have high road and rail traffic volumes.

In the second tier, we show the break up of the accidents caused due to intrusion against the level crossing gate, ignorance of warning and side hit. Sub-trees are not constructed for accidents caused due to clearance invasion, wheel wreck, engine stalling and traffic congestion due to the unavailability of data for these causes.

Figure 3-17 shows the sub-tree for accidents caused due to intrusion against the level crossing gate. Though the major reason for the intrusion is unclear, some accidents have occurred when the driver is not concentrating on the road, the driver is drunk, he is overspeeding or the vehicle slips due to snow.

Figure 3-18 shows the sub-tree for accidents caused due to ignorance of the level crossing warning. 68% of the automobile accidents have occurred when the driver has deliberately ignored the level crossing warning and gone into the crossing, but has not been able to come out on the other side. About 20% of the accidents have occurred when the driver did not hear the warning bell and unknowingly went into the crossing area. 3% of the accidents have occurred when cars went into the crossing after the warning bell stopped ringing and immediately started ringing as another train was approaching the crossing. This scenario is discussed in Section 4.2 in the analysis of the perceived actions of the road vehicles when they approach the crossing.

Figure 3-19 shows the sub-tree for accidents caused due to side hit. Driver mistake has accounted for about 60% of the accidents.

The various sub-causes of automobile accidents are categorized by the characteristics of the accident and tabulated. Table 3.11 shows the probabilities by cause when the driver was aware of the existence of the crossing and the on-coming train, but the accident occurred. This includes the major cause of accidents where the vehicle went into the crossing even though the warning bell was ringing, but could not get out (22.08%).

Table 3.12 shows the accidents due to vehicles caught in the crossing. 45% of the accidents have occurred due to wheel wreck, engine stalling and traffic congestion where the vehicle has legally entered the crossing.

Table 3.13 shows the accidents that have occurred due to the vehicle being unaware of the crossing.

Finally, Table 3.14 shows the accidents that have occurred due to driver mistake.

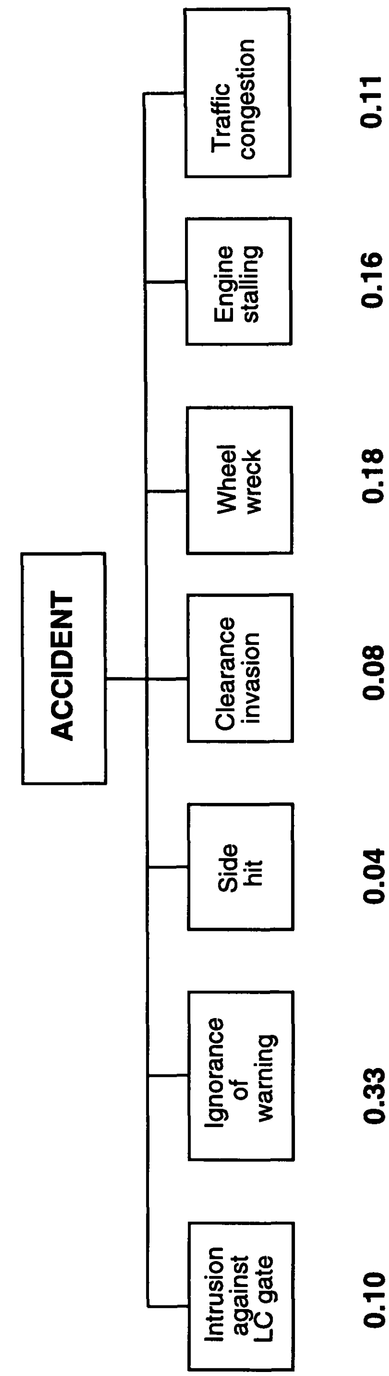


Figure 3-16: Causality tree for the level crossing accidents

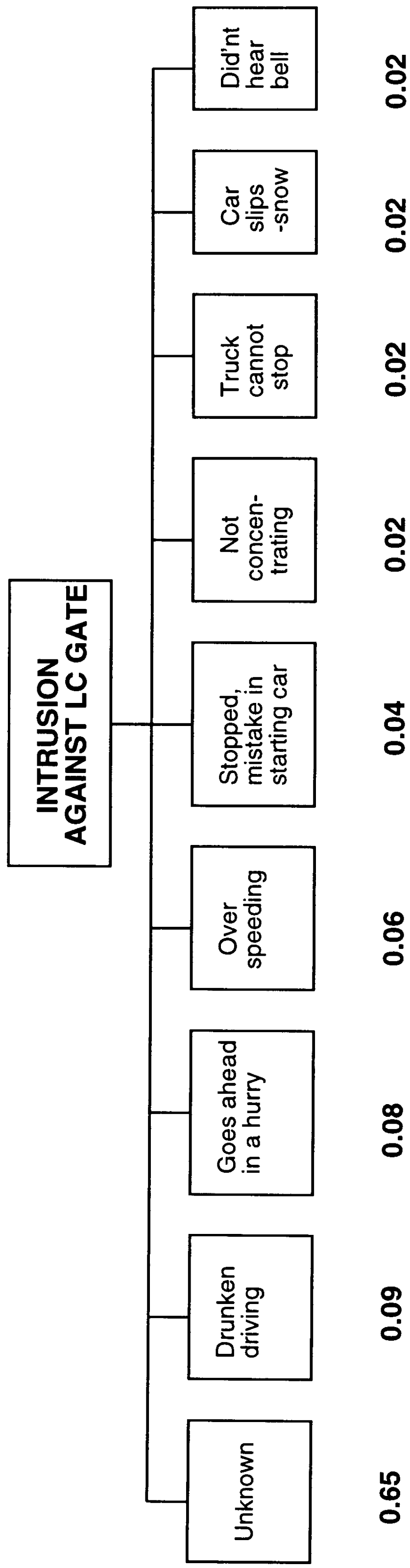


Figure 3-17: Intrusion against the level crossing gate subtree

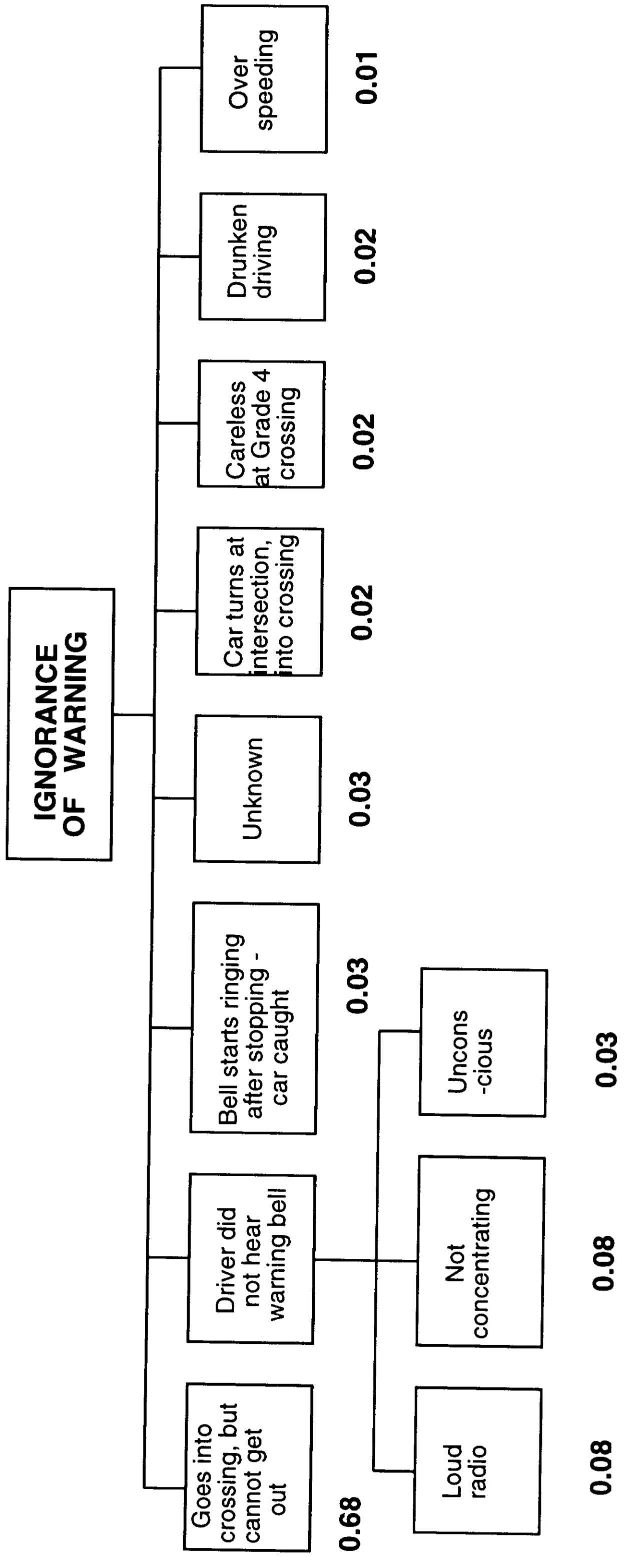


Figure 3-18: Ignorance of warning subtree

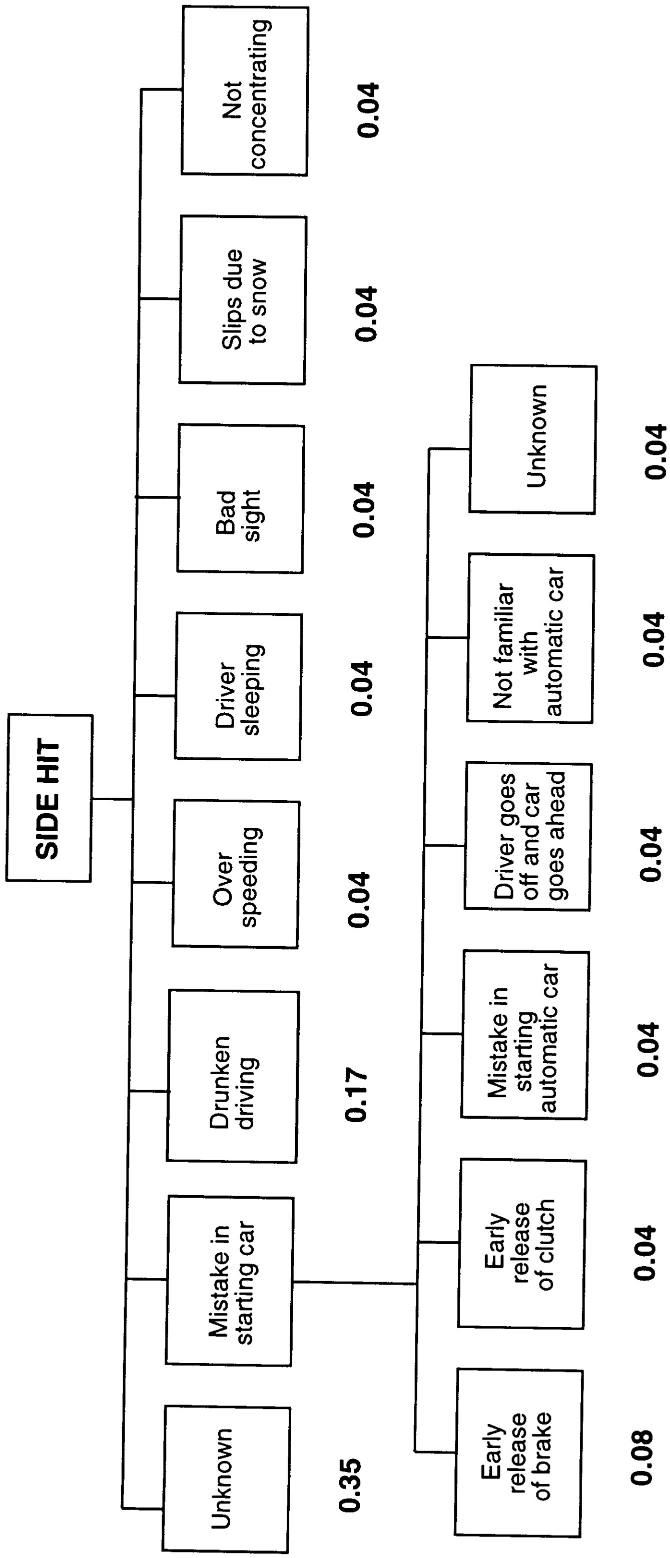


Figure 3-19: Side hit subtree

| Accident cause | Likelihood |
|---|---|
| Goes into crossing, cannot get out | 22.08% |
| Clearance invasion | 7.85% |

Table 3.11: Accidents caused though driver was aware of the crossing

| Accident cause | Likelihood |
|---|---|
| Wheel wreck | 18.25% |
| Engine stalling | 15.88% |
| Traffic congestion | 11.31% |

Table 3.12: Accidents caused due to vehicles caught in the crossing

| Accident cause | Likelihood |
|---|---|
| Driver does not hear bell (stereo on) | 2.92% |
| Unconscious | 1.09% |
| Car turns and goes into intersection | 0.55% |
| Driver sleeping | 0.18% |
| Bad sight | 0.18% |

Table 3.13: Accidents due to the driver being unaware of the crossing

| Accident cause | Likelihood |
|---|---|
| Not concentrating while driving | 2.91% |
| Drunken driving | 2.19% |
| Overspeeding | 1.10% |
| Momentary stop and start of warning bell | 1.09% |
| Goes ahead in a hurry | 0.73% |
| Goes ahead at Grade 4 crossing | 0.55% |
| Car is stopped but mistake in starting the car | 0.36% |
| Early release of brake | 0.36% |
| Car slips due to snow | 0.33% |
| Truck cannot stop as it is carrying heavy material | 0.18% |
| Car hits another car at crossing and intrudes | 0.18% |
| Early release of clutch | 0.18% |
| Mistake in starting automatic car | 0.36% |
| Driver gets off and car goes ahead | 0.18% |

Table 3.14: Accidents caused due to driver mistake

### 3.4.9 Accidents by time of day

Figure 3-20 shows the number of accidents that have occurred by time of the day. Accidents have occurred at all hours of the day, except during the morning hours of 12 AM to 5 AM when few (or no) trains are running.

## 3.5 Development of the methodology for the level crossing accident rates

The last two sections talk about the characteristics of the level crossings and the accidents that have occurred on these crossings. This sets the stage for establishing the equations for determining the accident rate and the monetary collective risk $R_m$ of a level crossing accident. The definition of the risk of an accident is composed of two parts:

- Accident rate
- Weighted average consequences per accident

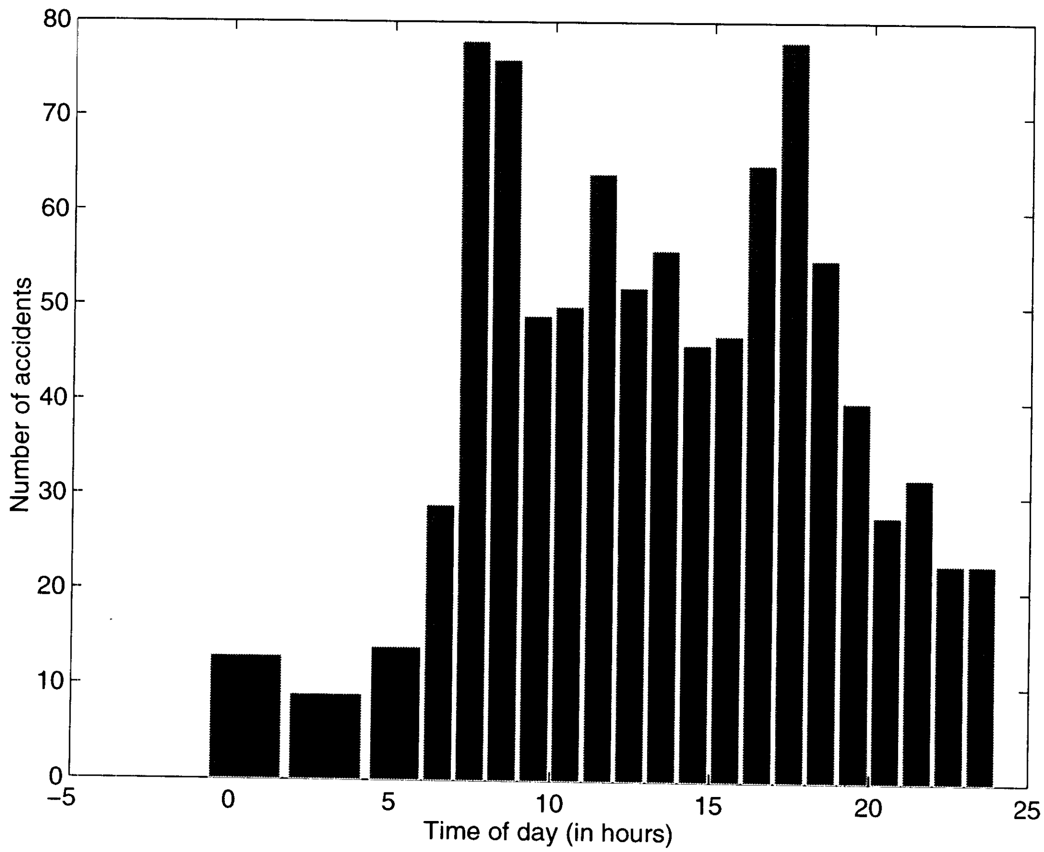


Figure 3-20: Accidents by time of day

### 3.5.1 Accident rate

Level crossing accidents are not a common occurrence at any intersection on the JR East system. The extremely safe operating environment has dramatically reduced the number of level crossing accidents to less than a hundred accidents per year. Thus, the accident rate is established for a group of level crossing accidents, with the crossings in the group having similar characteristics; rather than for a single accident at a level crossing. The accident rate $p_i$ for a level crossing accident with accident cause $i$ is defined as

$$p_i = \frac{Acc_i}{LC_i \times (RTV) \times (365) \times (P.e)} \tag{3.1}$$

where

$Acc_i$: Number of accidents occurring due to cause $i$

$LC_i$: Number of level crossings in the concerned group

$RTV$: Rail traffic volume per day

365: 365 days per year

$P.e$: Period of exposure, in years (the period of exposure is defined as the period in which the accidents have occurred at the crossings)

Thus, the accident rate gives the number of accidents per million trains going across the level crossing.

Some of the accident prediction formulas discussed in Chapter 1 use the product of the rail traffic volume and the road traffic volume to determine the accident rate of a level crossing accident. We use only the rail traffic volume as the denominator term to define the accident rate. Two reasons can be ascribed for this:

1. It corroborates the finding that crossings with low rail and highway traffic are riskier than those with high rail and highway traffic. Table 3.15 shows that this is indeed the case. An intuitive explanation for this is as follows. At the low rail traffic volume crossings, the road traffic volume is also low (a few hundred

vehicles per day at most) because these crossings are located in non-urban areas. Thus, a vehicle arriving at the crossing is likely to be the first vehicle at the crossing. This greatly increases its risk of being involved in an accident since it may ignore the warning and go into the crossing just as the train is coming. On the other hand, crossings with high rail traffic volume are located in urban areas which have high road traffic volumes (of the order of a few thousand vehicles per day). A vehicle arriving at this crossing is less likely to be the first vehicle. The chance of it ignoring the warning is also less since there are possibly vehicles in front of it which will stop at the warning bell (this is not to say that the vehicles in front will always stop, but the chance that two or three vehicles will ignore the warning is very slim). This is confirmed from the level crossing site visits done by the author.

2. It allows us to compare the accident rate at the crossing with respect to the different types of road traffic.

| RTV | #LC | #Acc | Acc. rate(per million trains) |
|---|---|---|---|
| 0-20 | 542 | 23 | 1.938 |
| 20-40 | 1852 | 111 | 0.913 |
| 40-60 | 1145 | 112 | 0.893 |
| 60-80 | 1181 | 102 | 0.563 |
| 80-100 | 564 | 56 | 0.504 |
| 100-120 | 672 | 69 | 0.426 |
| 120-160 | 565 | 85 | 0.490 |
| 160-200 | 411 | 87 | 0.537 |
| 200-400 | 765 | 175 | 0.348 |

Table 3.15: Accident rate as a function of rail traffic volume

### 3.5.2 Weighted average consequences per accident

We consider the following four as the consequences of a level crossing accident:

- Third party fatalities

- Third party injuries
- Train delays
- Train cancellations

Passenger fatalities and injuries have not been included since none of the level crossing accidents have resulted in injuries or deaths to passengers on the train. In addition to train delays and cancellations, disruptions of the road traffic can also be considered, but the road traffic does have alternate routes to get to their destinations unlike the rail traffic. In any case, disruption of road traffic does become an issue of concern in densely populated areas like Tokyo. The above mentioned consequences can be easily included in the definition of the weighted average consequences as an additive term. So, in the first step, the total consequences $c_i$ resulting from an accident due to cause $i$ can be defined as

$$c_i = \text{Fatalities} + \text{Injuries} + \text{Train delays} + \text{Train cancellations}$$

The collective risk $R$ can be defined as

$$R = \sum_{i=1}^{8} p_i c_i \tag{3.2}$$

where

$i$=1...8 are the eight accident causes, as defined in Section 3.2.2

$p_i$: Accident rate with cause $i$

$c_i$: Total consequences resulting from cause $i$

This definition of risk can be extended to include the risk conversion factors (RCF) that was discussed in Section 2.4.1. We do not attempt to determine the exact risk conversion factors, but draw upon the work done by Nasser [16] in the construction of the Safety Performance Index. Table 3.16 [16] shows the risk perception weights for

| | Risk Perception Weight |
|---|---|
| Passengers on board | 100 |
| Other passengers | 5 |
| Third-party persons | 1 |
| Sub-contracted workers | 5 |
| Employees on duty | 100 |
| Employees off duty | 100 |
| Delays | 1 |

Table 3.16: Risk Perception Weights for Different Outcomes

different outcomes. Since the level crossing accidents have not involved any casualties to passengers on board and have resulted in third party injuries and fatalities and train delays and cancellations, a risk conversion factor of 1 is appropriate for the consequences. Thus, $\varphi(c_i)$ is assigned a value 1 in the definition of the perceived risk $R_p$ and is given as

$$R_p = \sum_{i=1}^{8} p_i c_i \tag{3.3}$$

since

$\varphi(c_i) = 1$ in the definition of the perceived risk $R_p$

This definition of risk can be extended to include the marginal cost or the willingness-to-pay of the consequences of the crossing accidents. Let us address each consequence one by one.

1. Fatality: In this study, we do not explicitly determine the value of a life. We present a brief discussion of the work done by several researchers and the methodologies that have been developed to determine the value of a human life.

   Nasser [16] presents a comprehensive discussion of the two methodologies currently used to determine the value of a life: human capital theory approach and willingness-to-pay approach. The human capital theory approach centers around the premise that the value of a life is the cost to society from this loss of life. The willingness-to-pay approach treats risk as an economic good [16] and argues that an appropriate measure for risk reduction is the price that one is willing to pay to realise this reduction in risk. As shown in Table 3.17 [16] which shows the values of life used in selected circumstances in various countries, the willingness-to-pay approach provides higher estimates of the value of life than the human capital theory approach (more scattered). The US estimate is the value used by the Department of Transportation (DOT) in safety management programs.

Two approaches can be used to determine the amount that one is willing to

| Cost of Road Accident Death | value of life($) | Estimation Basis |
|---|---|---|
| United States | 2,600,000 | Willingness-to-pay |
| Sweden | 1,236,000 | Willingness-to-pay |
| New Zealand | 1,150,000 | Willingness-to-pay |
| Britain | 1,100,000 | Willingness-to-pay |
| Germany | 928,000 | Human capital theory |
| Belgium | 400,000 | Human capital theory |
| France | 350,000 | Human capital theory |
| Holland | 130,000 | Human capital theory |
| Portugal | 20,000 | Human capital theory |

Table 3.17: The Value of Life

pay to reduce his risk by a certain amount. They are:

(a) Revealed preferences (using data from the job market) [16]

(b) Stated preferences (using survey analysis) [16]

We do not present the details of the two approaches, but refer the interested reader to the discussion in Nasser [16].

The value of life shows significant variations across different countries (Table 3.17), the cultural background and the background risk.

For our study, we compare the estimates of the value of life arrived at by the Safety Research Laboratory of JR East, values used by transportation agencies around the world and those determined by Viscusi [16]. We then select the median estimate of the value of life.

JR East suggests an estimate of $256,000 for the value of a life [16]. This is close to the estimates in the lower half of Table 3.17 for the value of life in different countries. The United States uses a value of $2,600,000 based on the willingness-to-pay approach (Table 3.17). The scatter of these values suggests that the estimation of the value of a life is no mean task and points to the preliminary nature of the results. Thus, we use a median scenario of $1,000,000 as the estimate of the value of a life (corresponding to the intermediate scenario in Table 4.2 [16]).

2. Injury: The value of an injury is easier to determine than the value of a life since it is not associated with the ethics of determining what one's life is worth. The Safety Research Laboratory calculate the value of an injury to be $10,000 or 1 million yen [16]. We use this estimate to be the marginal cost of an injury.

3. Train delay: Nasser [16] determines the cost of train delays to be $200 per hour and $20 per hour as the value of passenger's time. The mean delay time of a crossing accident is 30 minutes. This gives the total cost of a train delay (for a train with 1000 passengers) to be $10,000 or 1 million yen.

4. Train cancellation: A train cancellation warrants the provision of either a refund of the ticket (determined as $10 [16]) or alternate service to the passengers as a result of the cancellation (determined as $ 60 [16]). We consider a mean value of $40 as the value of a refund. A train cancellation which results after a 2 hour train delay has a cost of around $80,000 or 8 million yen. Thus, we assign a marginal cost of 10 million yen to a train cancellation.

The monetary collective risk, $R_m$, can be given as

$$R_m = \sum_{i=1}^{8} p_i \times [100 \times (fa_i) + 1 \times (in_i) + 1 \times (td_i) + 10 \times (tc_i)] \qquad (3.4)$$

where

$fa_i$: third party fatality

$in_i$: third party injury

$td_i$: train delay

$tc_i$: train cancellation

## 3.6 Analysis of the crossings and accidents

This section looks at possible relationships between the level crossing attributes and the accidents that have occurred at these crossings. The analysis is not exhaustive, in the sense that it does not cover all possible crossing attributes. Instead, we present a few examples and show how these relationships can be established for any of the crossing attributes.

### 3.6.1 Comparison by grade of the crossing

Table 3.18 shows the percentage of crossings and accidents that correspond to the different level crossing grades. Grade 3 and Grade 4 crossings have had more than their share of accidents. 4.7% of the crossings are Grade 3, whereas they have had 7% of the accidents; 10.3% of the crossings are Grade 4 and they have had 17% of the accidents.

### 3.6.2 Comparison by visibility of the crossing

Figure 3-21 shows the distribution of the minimum visibility on the left and right at all crossings and crossings where accidents have occurred. The visibility at all the crossings is approximately lognormally distributed. The mean visibility is almost the

| Crossing grade | %Cr. | %Acc. | %Acc./%Cr. |
|---|---|---|---|
| Grade 1 | 85 | 76 | 0.894 |
| Grade 3 | 4.7 | 7 | 1.489 |
| Grade 4 | 10.3 | 17 | 1.650 |

Table 3.18: Crossings and accidents by grade of the crossing

same in both cases. In section 3.7.1, we will develop the accident rates on the basis of the visibility of the crossing.

### 3.6.3 Comparison by the width of the crossing

The width of the crossing refers to the number of tracks present in the crossing. Crossings with single or double tracks have fewer number of accidents since a significant number of them are Grade 3 or Grade 4 crossings through which automobiles do not go through. Table 3.19 shows the percentage of crossings and accidents for different widths of the crossing.

| #Tracks | %Cr. | %Acc. | %Acc./%Cr. |
|---|---|---|---|
| 1 | 66.2 | 48.6 | 0.734 |
| 2 | 30.8 | 42.1 | 1.367 |
| 3 | 1.2 | 2.7 | 2.250 |
| 4 | 1.0 | 2.5 | 2.500 |
| >= 5 | 0.8 | 4.1 | 5.130 |

Table 3.19: Crossings and accidents by number of tracks

### 3.6.4 Comparison by location of the crossing

90% of the accidents have occurred in residential and rural areas and they account for 94% of the crossings. But residential areas have had more than their share of accidents (32% of the crossings are in residential areas and they have had 48.3% of the accidents). Table 3.20 shows the percentage of crossings and accidents by the location of the crossing.

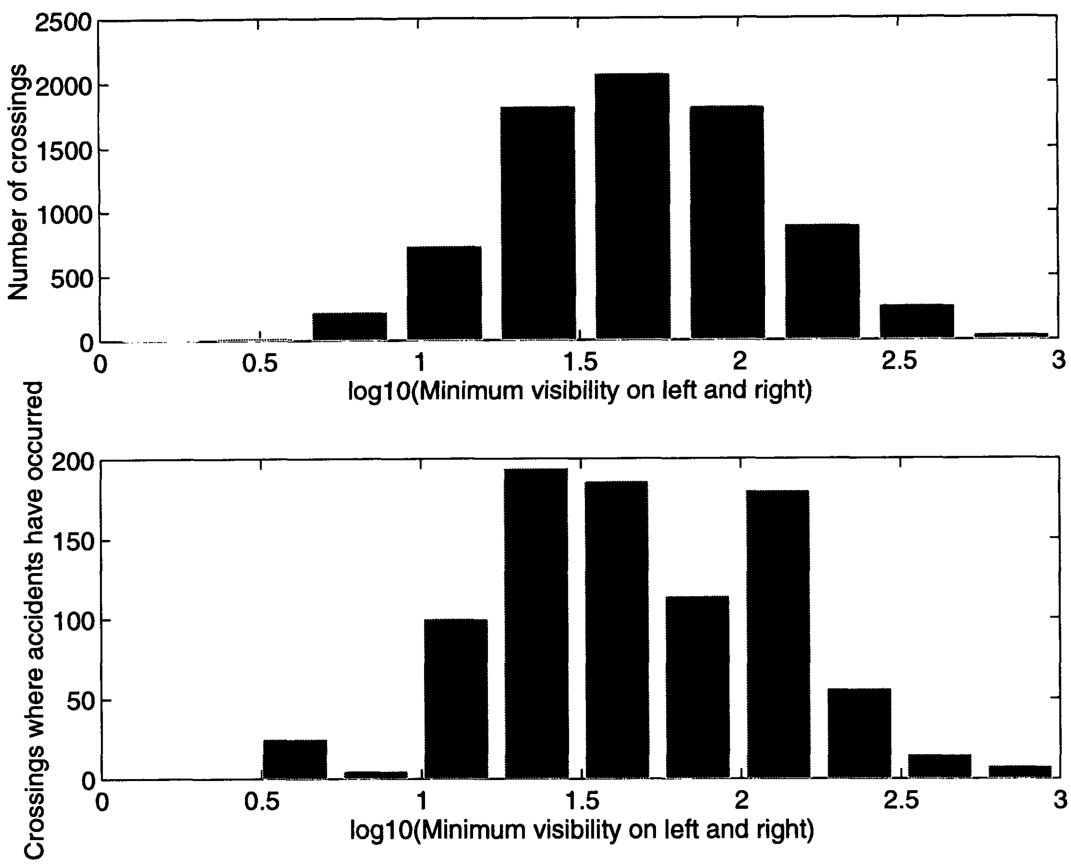


Figure 3-21: Crossings and accidents by visibility of the crossing

| Location | %Cr. | %Acc. | %Acc./%Cr. |
|---|---|---|---|
| Rural | 61.8 | 43.4 | 0.702 |
| Residential | 32.0 | 48.3 | 1.519 |
| Commercial | 3.3 | 4.8 | 1.455 |
| Industrial | 2.7 | 3.2 | 1.185 |

Table 3.20: Crossings and accidents by location of the crossing

### 3.6.5 Comparison of the crossing distance to the nearest intersection and accidents due to traffic congestion

Figure 3-22 shows that almost 50 of the 65 accidents caused due to traffic congestion are at crossings where the distance to the nearest intersection is less than 5m, which is consistent with the fact that 80% of the crossings are less than 5m from the nearest road intersection on either side.

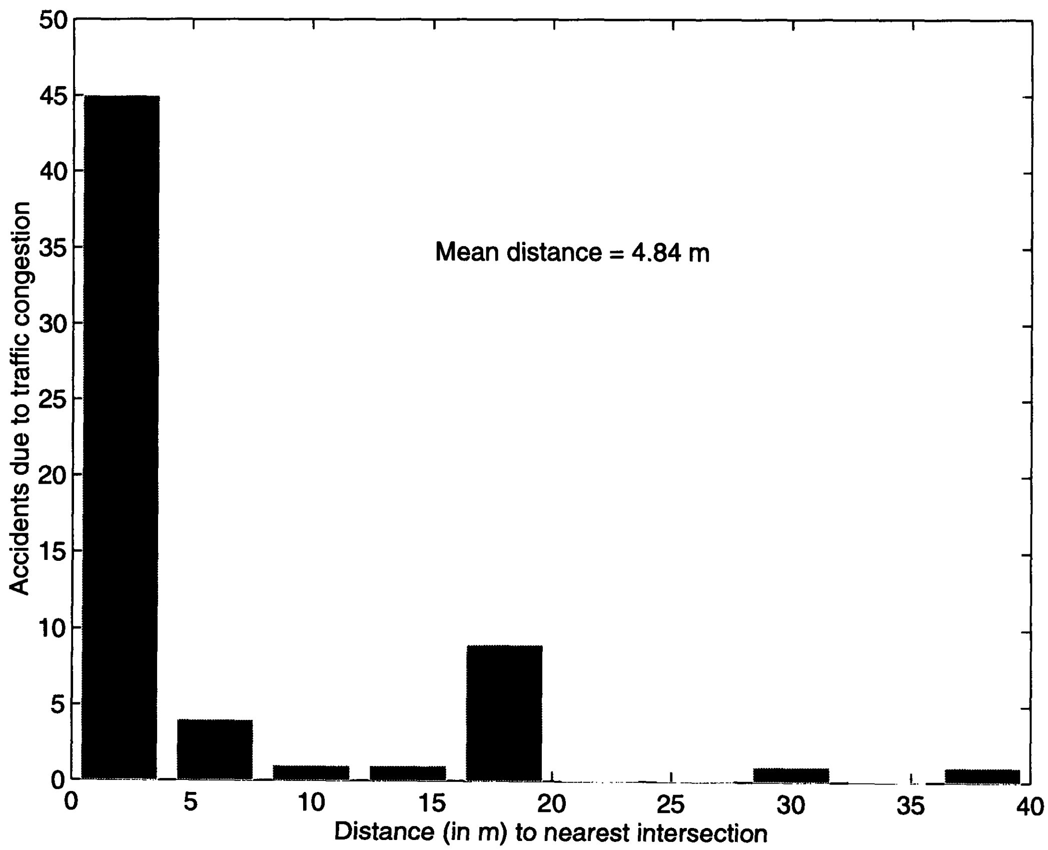


Figure 3-22: Traffic congestion accidents v/s distance to nearest intersection

## 3.7 Accident rate and the risk

In this section, we look at the variation in the accident rate and the monetary collective risk $R_m$ across the different level crossing attributes such as visibility and road gradient, and the various safety devices at the crossing.

### 3.7.1 Visibility of the crossing

The accident rate (per million trains) is higher when the visibility of the crossing is lower, but it is significant only for crossings with very low visibilities (of 20m or less). The accident rates are more or less the same for crossings with visibilities greater than 20m. Table 3.21 shows the accident rate for crossings with visibility less than 20m and visibility greater than 20m. The mean accident rate for crossings with visibility less than 20m is 0.705 (per million trains) and is 0.509 (per million trains) for crossings with greater than 20m visibility. The difference in the rates is statistically significant (as described in Section D.2).

Another issue that is related to the visibility of the crossing is the road traffic volume at the crossing. We reinforce the argument made in Section 3.5 that low rail traffic volume crossings are riskier than high rail traffic volume ones. Table 3.22 shows the accident rate (per million automobiles) by visibility for three categories of road traffic volume. These accident rates are established for Grade 1 crossings without obstacle detectors. The accident rate is highest for crossings with low road traffic (0-100 vehicles per day) and decreases by a factor of 10 as the road traffic increases (100-1000 vehicles per day) and further reduces by a factor of 10 for high road traffic (1000-10000 vehicles per day). The difference in the accident rates is highly significant (the null hypothesis is rejected at $p=0.01$). Thus, crossings with low road traffic are riskier to road users than those with high road traffic. Since low road traffic crossings also have fewer trains, low rail traffic volume crossings are riskier than high rail traffic volume ones.

| | Accident rate (per million trains) | |
|---|---|---|
| RTV | 0-20m | >20m |
| 0-40 | 1.096 | 0.828 |
| 40-80 | 0.725 | 0.537 |
| 80-120 | 0.559 | 0.309 |
| 120-160 | 0.441 | 0.361 |

Table 3.21: Accident rates by visibility of the crossing

| | Accident rate (per million automobiles) | | |
|---|---|---|---|
| Visibility(m) | 0-100 | 100-1000 | 1000-10000 |
| 0-20 | 0.395 | 0.040 | 0.006 |
| 20-50 | 0.252 | 0.028 | 0.003 |
| 50-100 | 0.170 | 0.020 | 0.005 |
| >100 | 0.151 | 0.020 | 0.004 |

Table 3.22: Accident rates by road traffic volume and visibility

### 3.7.2 Road gradient

The road gradient is defined as the gradient of the road leading to the level crossing. The gradient can either be level, upward or downward. Table 3.23 shows the accident rate for four categories of rail traffic volume and for two categories of the road gradient (level and not level). In general, the accident rate is higher as the gradient is either upward or downward. The mean accident rate for a level road is 0.427 per million trains and is 0.550 per million trains for a road with gradient. The difference in the accident rates is statistically significant (as shown in Section D.3).

### 3.7.3 Crossings by grade, but without obstacle detector

Figure 3-23 shows the variation in the accident rate across the three level crossing grades [14]. Grade 1 crossings are safer than Grade 4 crossings, which are in turn safer than Grade 3 crossings. Even though Grade 3 crossings are equipped with a warning system, they are present throughout the JR East network and have a considerable amount of road traffic going through. By contrast, most of the Grade 4 crossings are

| | Accident rate (per million trains) | |
|---|---|---|
| RTV | Level | Not level |
| 0-40 | 0.716 | 0.833 |
| 40-80 | 0.280 | 0.626 |
| 80-120 | 0.258 | 0.357 |
| 120-160 | 0.455 | 0.382 |

Table 3.23: Accident rates by road gradient

located in rural areas and have just a few trains and road vehicles going by everyday. In addition, most of the traffic going through is either pedestrian or bicycle traffic leading to a lower accident rate than Grade 3 crossings.

At low rail traffic volumes, the accident rate is the lowest for Grade 1 crossings and the highest for Grade 3 crossings. The accident rate drops as the rail traffic volume increases and then steadies out. The mean accident rate at Grade 1 crossings is 0.588 per million trains, for Grade 3 crossings is 1.250 per million trains and is 0.758 per million trains at Grade 4 crossings.

The collective risk $R_m$ (per million trains) follows the same pattern as the accident rate and is the highest for Grade 3 crossings (Figure 3-23). Since the consequences increase with increasing rail traffic volume, the risk has a steady value as the accident rate is decreasing with increasing rail traffic. The mean risk at Grade 1 crossings is 45 million yen (per million trains), 103 million yen (per million trains) at Grade 3 crossings and is 61 million yen (per million trains) at Grade 4 crossings.

### 3.7.4 Crossings by type of barrier, but without obstacle detector

Crossings with semiautomatic-automatic barrier are slightly safer than those equipped with automatic barrier (Figure 3-24) [14]. The accident rate is higher for the low rail traffic volume crossings, and steadily drops with increasing rail traffic. The mean accident rate for crossings with automatic barrier is 0.623 per million trains and is 0.601 per million trains for crossings with semiautomatic automatic barrier (the

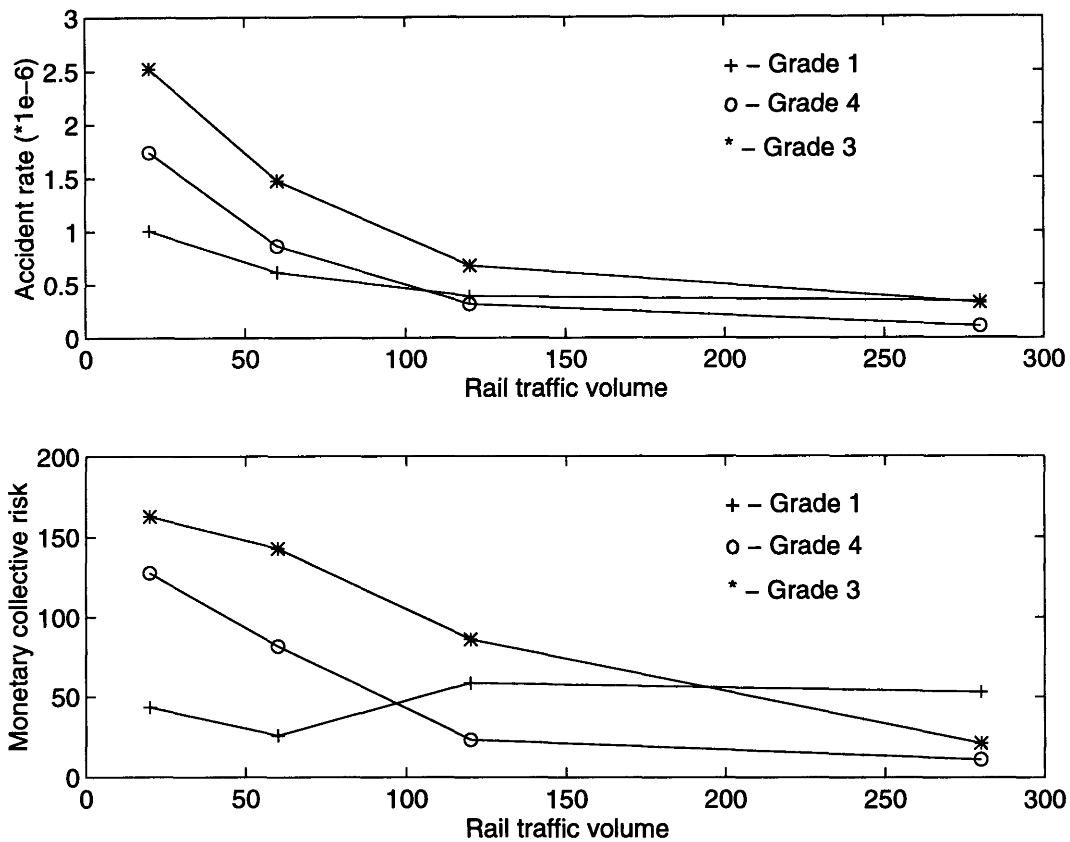


Figure 3-23: Accident rate and the collective risk for crossings without obstacle detector

difference in the accident rates is not statistically significant).

The risk has a steady value across rail traffic and is slightly lower for crossings with semiautomatic-automatic barrier ( 3-24). The mean risk for crossings equipped with an automatic barrier is 50 million yen (per million trains) and is 36 million yen (per million trains) for crossings with semiautomatic automatic barrier.

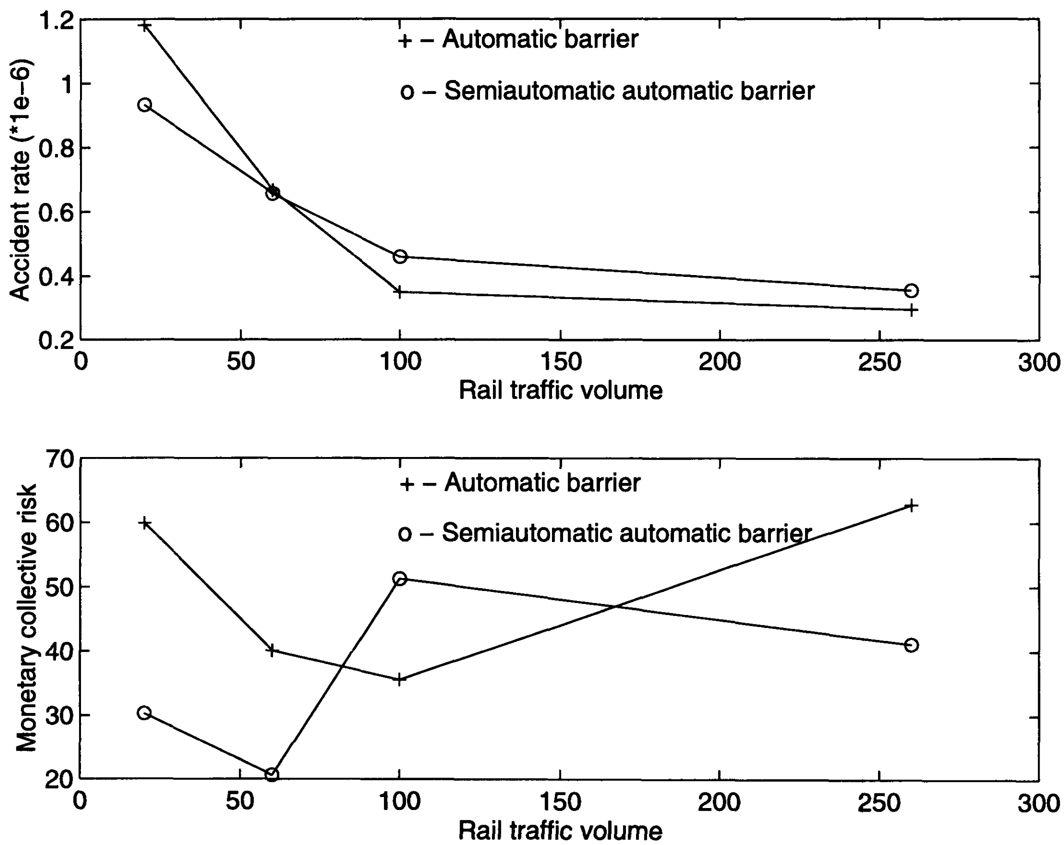


Figure 3-24: Accident rate and the collective risk for crossings by type of barrier

### 3.7.5 Crossings equipped with obstacle detector

The installation of obstacle detectors has helped in reducing accidents at level crossings (as shown in Figure 3-25) [14]. The mean accident rate reduces from 0.428 per million trains to 0.123 per million trains at the crossings after the installation of detectors (this difference is statistically significant as shown in Section D.4). The monetary collective risk reduces by a factor of 7 at crossings with the detector (the risk decreases from 54 million yen (per million trains) to 7 million yen (per million trains)).

### 3.7.6 Crossings by grade, and equipped with obstacle detector

Obstacle detectors have been very effective in reducing the number of accidents at Grade 1 crossings (as shown in Figure 3-26) [14]. The mean accident rate reduces by nearly a factor of 10 at crossings where obstacle detectors are installed. The mean rate decreases from 0.479 per million trains to 0.060 per million trains and is statistically significant (the null hypothesis is rejected at $p=0.01$). The monetary collective risk decreases from 59.62 million yen (per million trains) to 3.55 million yen (per million trains) and is significant ($p=0.01$).

### 3.7.7 Crossings by type of safety device and road traffic

This analysis looks at the variation in the accident rate and the monetary collective risk at crossings grouped by the type of safety device present at the crossing (Grade 1 crossing with automatic barrier, Grade 1 crossing with semiautomatic automatic barrier, Grade 3 crossing and Grade 4 crossing) and the road traffic involved in the accident (passenger automobile, freight truck, motorcycle, bicycle, pedestrian and light vehicle). We do not present the detailed analysis here, but include it in Appendix 3 of the thesis. This data is included as an input to the risk model discussed in Chapter 4. Figure 3-27 shows a schematic diagram of the analysis that we have carried out for the crossings by type of safety device and the road traffic involved in the accident.

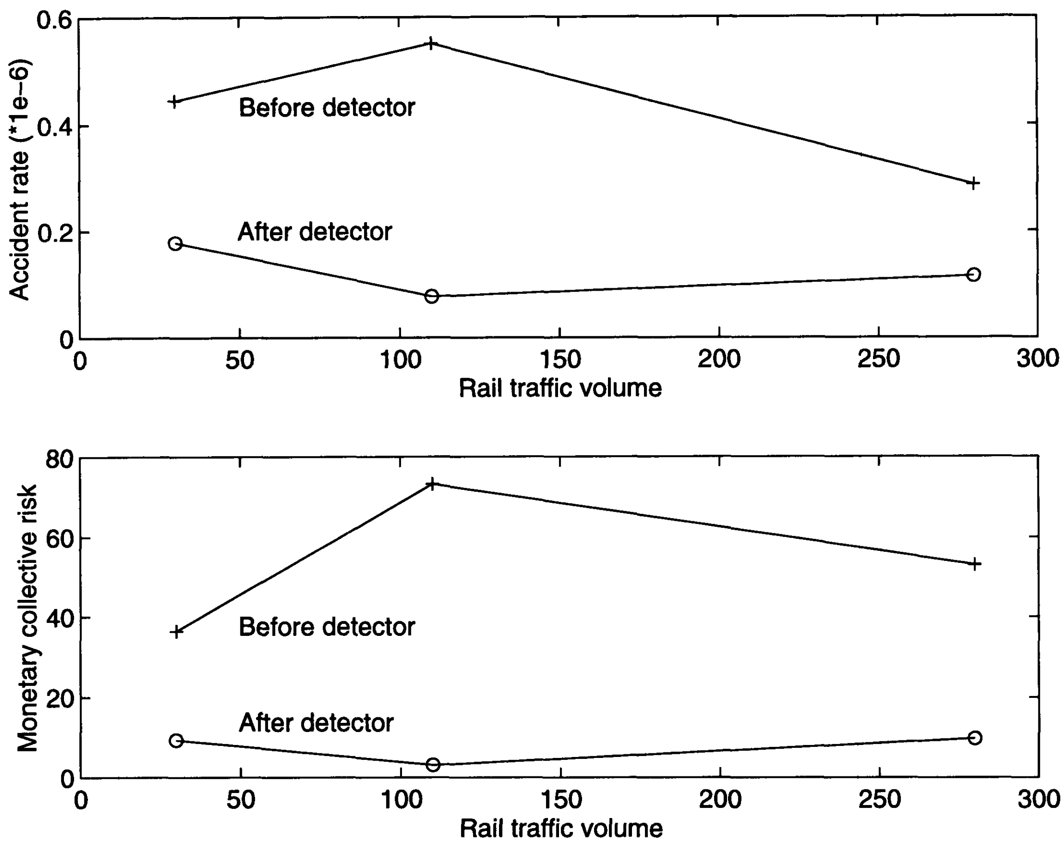


Figure 3-25: Accident rate and the collective risk for crossings with obstacle detector

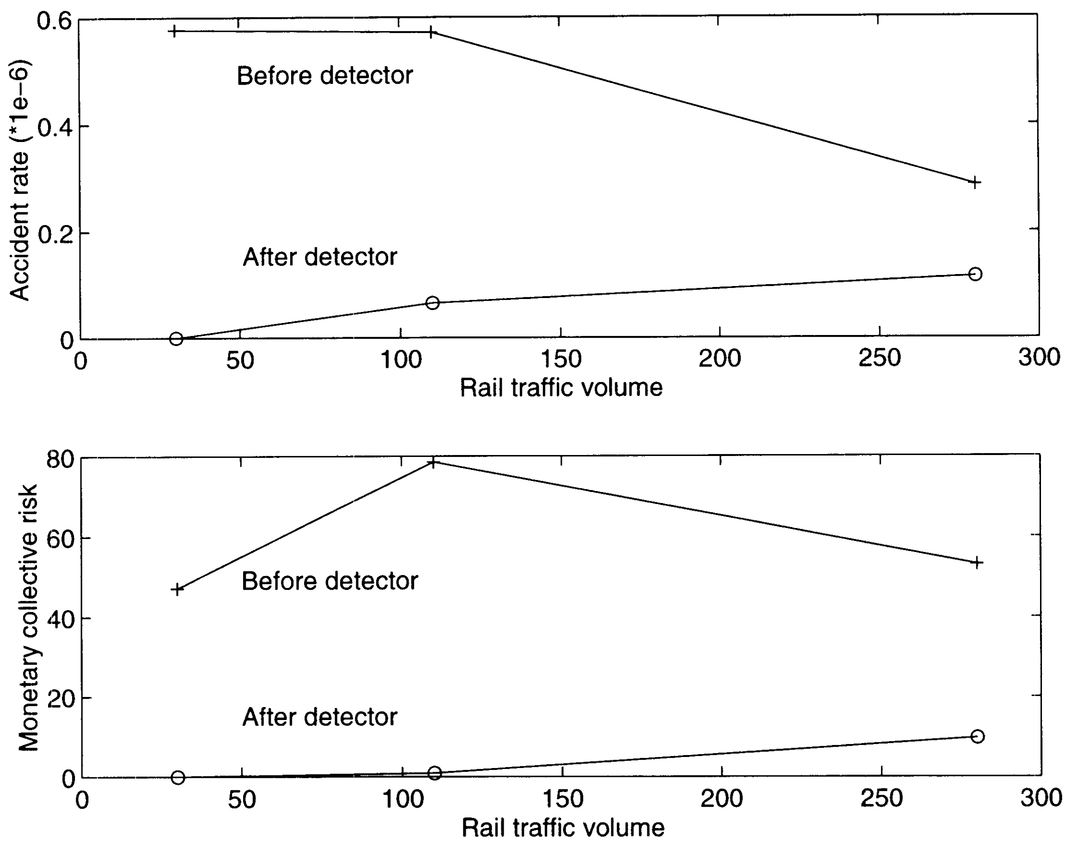


Figure 3-26: Accident rate and the collective risk at Grade 1 crossings without obstacle detector

| | No detector | Before detector | After detector |
|---|---|---|---|
| Automatic barrier | 1 to 6 | 1 to 6 | 1 to 6 |
| Semiautomatic automatic barrier | 1 to 6 | 1 to 6 | 1 to 6 |
| Grade 3 crossing | 1 to 6 | 1 to 6 | 1 to 6 |
| Grade 4 crossing | 1 to 6 | 1 to 6 | 1 to 6 |

1: Rail traffic volume and automobile traffic volume
2: Rail traffic volume and freight truck traffic
3: Rail traffic volume and motorcycle traffic
4: Rail traffic volume and bicycle traffic
5: Rail traffic volume and pedestrian traffic
6: Rail traffic volume and light vehicle traffic

Figure 3-27: Accident rate and the collective risk for crossings by type of safety device and road traffic involved in the accident

## 3.8 A first order estimate of catastrophic accidents

Accidents that result in catastrophic consequences have a very low probability of occurrence. But the occurrence of such accidents cannot be ruled out, since the risk of such an accident is not "zero." The level crossing accidents on the JR East network have resulted in minor consequences for the people standing by the crossing and negligible consequences for the people on board the train. These accidents can become catastrophic if it involves a collision between a train and a large vehicle such as a truck or a bus, and the effect can be compounded if the crossing is located in an urban area. In fact, level crossing accidents that have occurred with major consequences around the world have involved either a truck or a bus hitting the train [2].
The difficulty associated with estimating the likelihood of these accidents is that accidents of such a nature have never occurred on the JR East network. Thus, determining the probability of such accidents is no mean task. The following guidelines can be used to estimate the probability [7]:

1. "Estimates of "the" probability of an accident must include, explicitly or implicitly, contributions from all the possible sources of the accident."

2. "The widest related base of potential accident experience (exposure) should be surveyed for indications about the probability of an accident for a particular kind of experience."

3. "The combination of estimates of probability in parts of a system to reach overall estimates of probability is subject to subtle errors and must be carefully reviewed."

4. "Possible sources of error and uncertainty in estimates should be explicitly considered and, whenever possible, estimated quantitatively."

5. "Estimates of probabilities should be reported in ways not likely to mislead."

6. "Judgmental estimates of accident probabilities face difficulties of reasoned substantiation and provide numerous opportunities for bias. Their basis in evidence may not be explicit but should be free of mistakes and clear biases."

### 3.8.1 Procedure for estimating the risk

The following procedure is used to determine an upper bound on the risk of a catastrophic level crossing accident on the JR East network:

1. Determine the accident rate (per million trains) of a level crossing accident involving trucks and buses.

2. Find the weighted average consequences (i.e. consequences with the weights as defined in Section 3.5.2) of an accident involving trucks and buses.

3. Find the risk of an accident involving trucks and buses. This risk gives an upper bound to the risk of a catastrophic accident at a level crossing since the accident rate is an upper bound on the probability of a catastrophic accident and the consequences consider the worst scenarios of level crossing accidents around the world.

### 3.8.2 Calculation of the risk

To calculate the accident rate (per million trains) of an accident involving trucks and buses, we look at the level crossing accidents on the JR East network that have involved large trucks and buses. Assuming a mean rail traffic volume of 90 trains per day, the accident rate for trucks is 0.026 per million trains and 0.012 per million trains for buses. These accident rates give an upper bound to the probability of a catastrophic accident involving trucks and buses since an accident with large consequences has a lower likelihood than an accident with lower consequences.
The consequences of a catastrophic accident involving trucks and buses are determined from the Global Accident Database for level crossings maintained by Ernst Basler and Partners, Switzerland [2]. This database gives a list of 50 of the worst

level crossing accidents that have occurred between 1981 and 1994. These accidents have mainly been collected from media reports. Of course, the database may not be comprehensive in terms of including all the worst accidents, but it gives an idea of the consequences of accidents with large trucks and buses. Thus, the weighted average consequences of an accident involving trucks (from a total of 20 accidents) is 92,570 million yen and buses (from a total of 30 accidents) is 20,975 million yen. Trucks have higher weighted consequences than buses as truck accidents have involved higher passenger fatalities than bus accidents.

This gives the monetary collective risk $R_m$ of an accident involving trucks to be 2.4 billion yen (per million trains) and buses to be 0.24 billion yen (per million trains). As discussed above, these risks give an upper bound to the risk of a catastrophic level crossing accident on the JR East network.

# Chapter 4

# A Risk Model for the Level Crossing Accidents

## 4.1 Importance of human factors

Human factors play a crucial role in determining the causal factors behind level crossing accidents. 53% of the accidents at crossings have occurred due to intrusion against the level crossing gate, ignorance of the level crossing warning and illegally going through a Grade 4 level crossing (going through the crossing without confirming whether a train is coming or not). These accidents have a significant contribution from the human side, in addition to the different attributes of the crossing. Besides, the nature of these accidents makes it difficult to be prevented by the obstacle detector which has been very successful in reducing the accidents caused due to wheel wreck, engine stalling and traffic congestion. Also, the accident causality analysis carried out in Section 3.4.8 shows that 22% of the automobile accidents have occurred when the vehicle has gone into the level crossing after the warning bell starts ringing, but has been unable to come out of the crossing. This can happen due to many reasons:

1. The vehicle may go into the crossing as the barrier is almost down, and the driver may panic resulting in the vehicle stopping in the middle of the crossing.

2. The vehicle may be involved in a wheel wreck, resulting in it getting caught in the crossing.

Thus, the above arguments suggest that the human factors of the driver are a very important component of the level crossing accidents. To that end, we decided to observe a few level crossings on the JR East network and get a feel for the perceived actions of the road vehicles at the crossing. This was done during my internship at JR East in the summer of 1995. I observed two Grade 1 crossings in the Tokyo area.

1. Crossing located near Kunitachi station, on the Chuo Line. We will refer to this crossing as Crossing I.

2. Crossing located near Kamata station, on the Tokaido and Keihin-Tohoku Lines. We will refer to this crossing as Crossing II.

I observed Crossing I in the morning peak hours of 8.00AM to 10.00AM. I observed Crossing II in the evening peak hours of 5.30 PM to 7.00PM and in the night time from 9.30PM to 11.00PM.

Our interest was on observing the behavior of the road traffic at the crossing, so we observed the traffic from both the directions going across the crossing. The flow of traffic was recorded on tapes and later analyzed at MIT.

The analysis focussed on answering the following questions:

1. How many road vehicles went through the crossing as the level crossing warning bell started ringing?

2. How many road vehicles went through the crossing as the barrier started coming down?

3. Were there any striking characteristics by type of road traffic?

4. How did the answers to the above questions compare across the two crossings observed?

Before carrying out the analysis, let us look at the working of a typical Grade 1 level crossing (shown in Figure 4-1) and the possible avenues for accidents to occur.

At a typical Grade 1 level crossing, the warning bell starts ringing 31 seconds before the train reaches the crossing and continues for 4 seconds. The barrier on the left side of the road starts coming down and is down after 6 seconds (21 seconds before the train reaches the crossing). Now, the barrier on the right side of the road starts coming down and is down in 6 seconds (15 seconds before the train reaches the crossing). Any vehicles that enter the crossing before the left side barrier comes down are not in any danger since the train is 21 seconds away from the crossing, and they have sufficient time to get to the other side. It may so happen that the vehicle may get stuck by the side of the crossing or its engine may stop in the event of which an accident is possible. The working of the crossing is a function of the speed of the trains going past the crossing. Higher speed trains need greater response times, so the warning bell starts ringing about a minute before the train reaches the crossing. During the level crossing site visits, we did not see any vehicles going on the wrong side of the road (except bicycles) in around 100 instances of the descent of the barrier. So, the likelihood of any vehicles going into the crossing as the right side barrier is coming down is quite small, except bicycles which do go through. At a high road traffic volume crossing, there are vehicles every few seconds. Thus, the chance of a vehicle going into the crossing as the left side barrier is coming down reduces greatly since there are possibly many vehicles in front of it which will stop at the warning sign. The above arguments imply that there is a 20 second "danger interval" (the interval when the right side barrier starts coming down till the train reaches the crossing) when a vehicle can go into the crossing, and the risk is a function of the vehicle headway during this interval. This notion of the "danger interval" is discussed in the risk model presented in Section 4.3.

## 4.2 The Analysis

A study of the road and rail traffic volume at Crossing I shows the high volume of traffic at the crossing in the morning peak period (8.00 AM to 10.00 AM). Figure 4-2 shows the variation by type of road traffic at the crossing, where each bar shows the

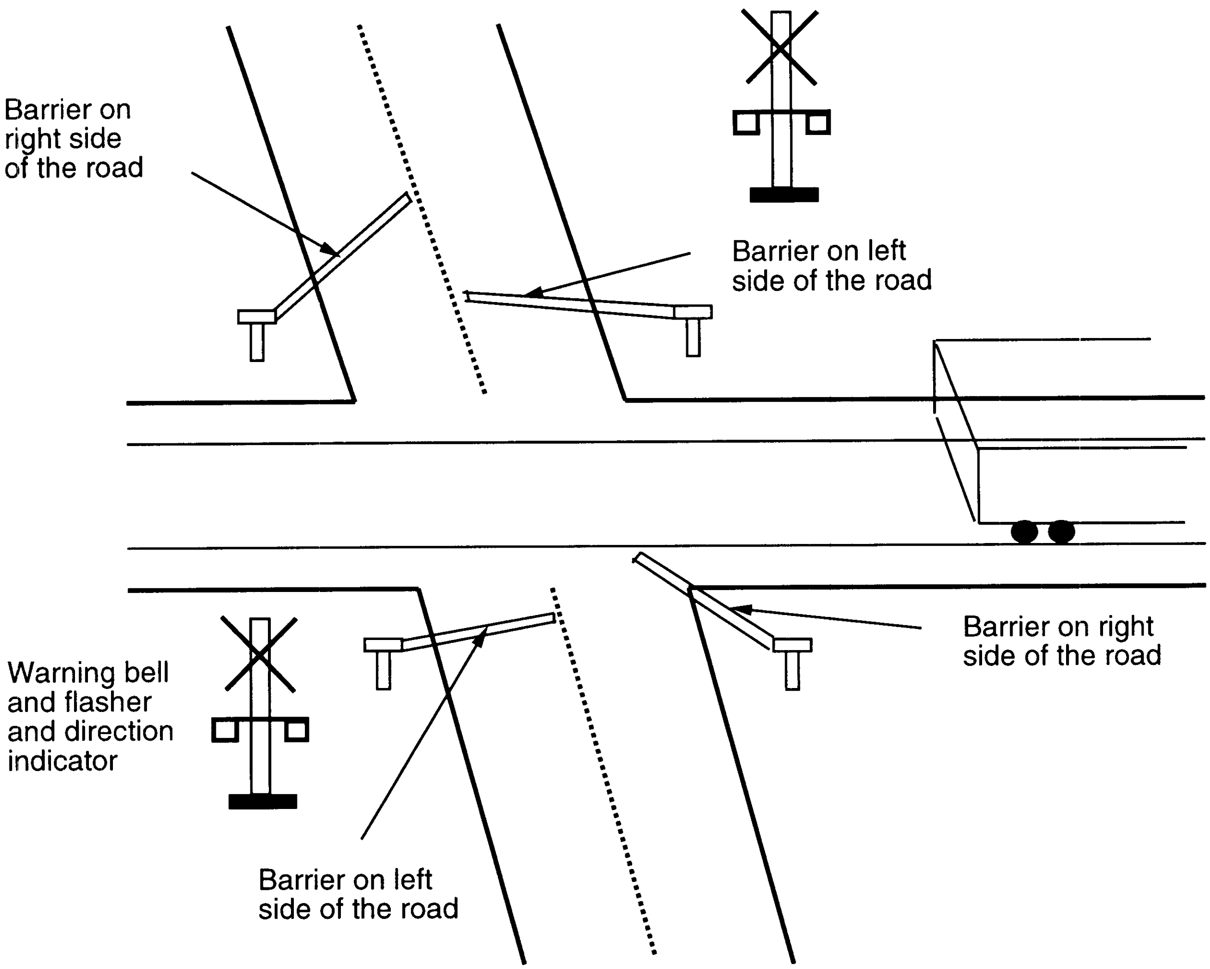


Figure 4-1: Schematic diagram of a typical Grade 1 level crossing

number of vehicles in a particular 30 minute interval (the intervals are plotted on the x-axis). On average, the number of automobiles at this crossing was much higher than that of the other vehicles during this period. The rail traffic volume was also high and trains went past the crossing every 2-3 minutes, and the barrier came down every 2-3 minutes (Figure 4-3).

The road traffic at Crossing II has a similar pattern as Crossing I with the automobile traffic much higher than the other types of traffic. The bicycle traffic at this crossing was much higher than that at Crossing I. The variation by road traffic is shown in Figure 4-4. Trains passed every 2 minutes at this crossing, and the barrier came down every 2 minutes (Figure 4-5).

To analyze the perceived actions of the road vehicles, we attempted to answer the following questions:

1. What is the probability that the first vehicle arriving at the crossing went through as the warning bell was ringing?

2. What is the probability that a second vehicle went through the crossing after the warning bell started ringing (this can happen either if the first vehicle went through or the first vehicle stopped)?

3. What is the probability that a vehicle went through the crossing as the barrier started coming down?

4. What is the probability that a second vehicle went through the crossing as the barrier was coming down?

5. Were there any vehicles that went through the crossing after the barrier on the left side of the road was down?

We answered each of the above questions by constructing probability trees to show the chance that a vehicle went through the crossing. We also did this by type of traffic to observe the variation in the perceived attitudes by the type of traffic at the crossing.

Let us first look at the actions of the road users at Crossing I.

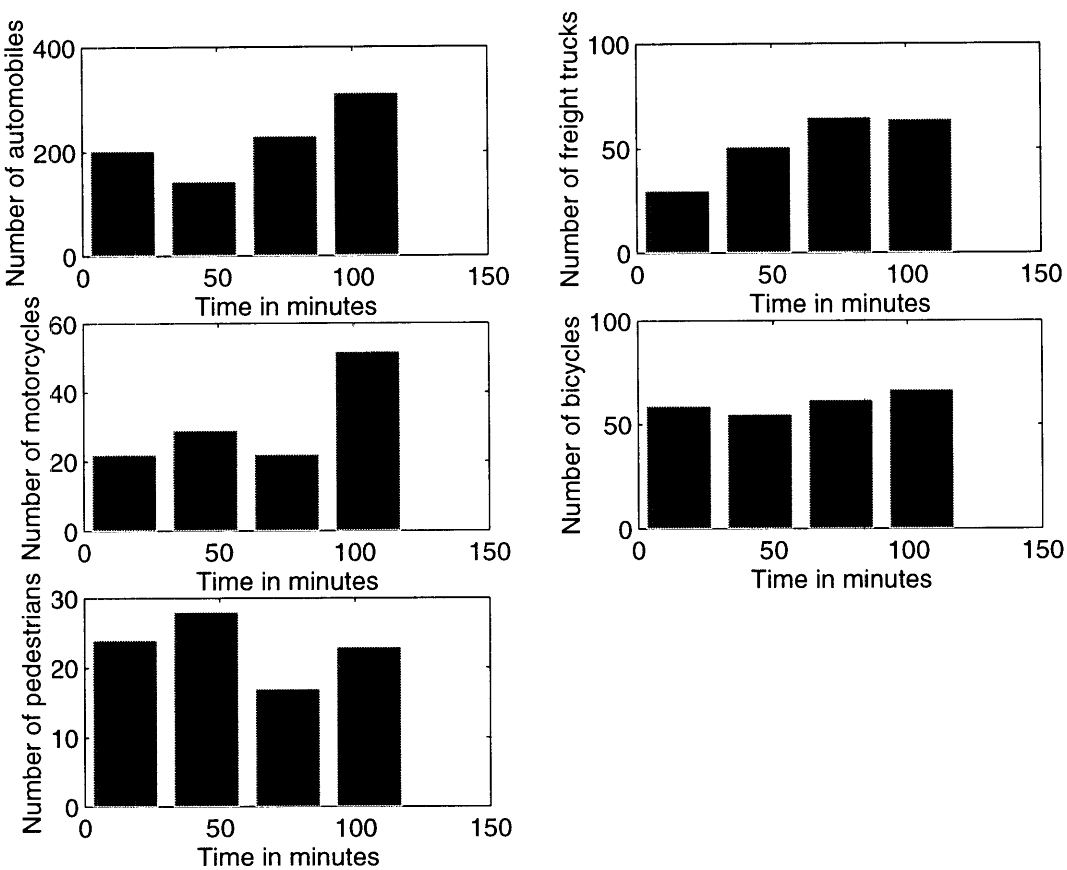


Figure 4-2: Variation by road traffic at Crossing I

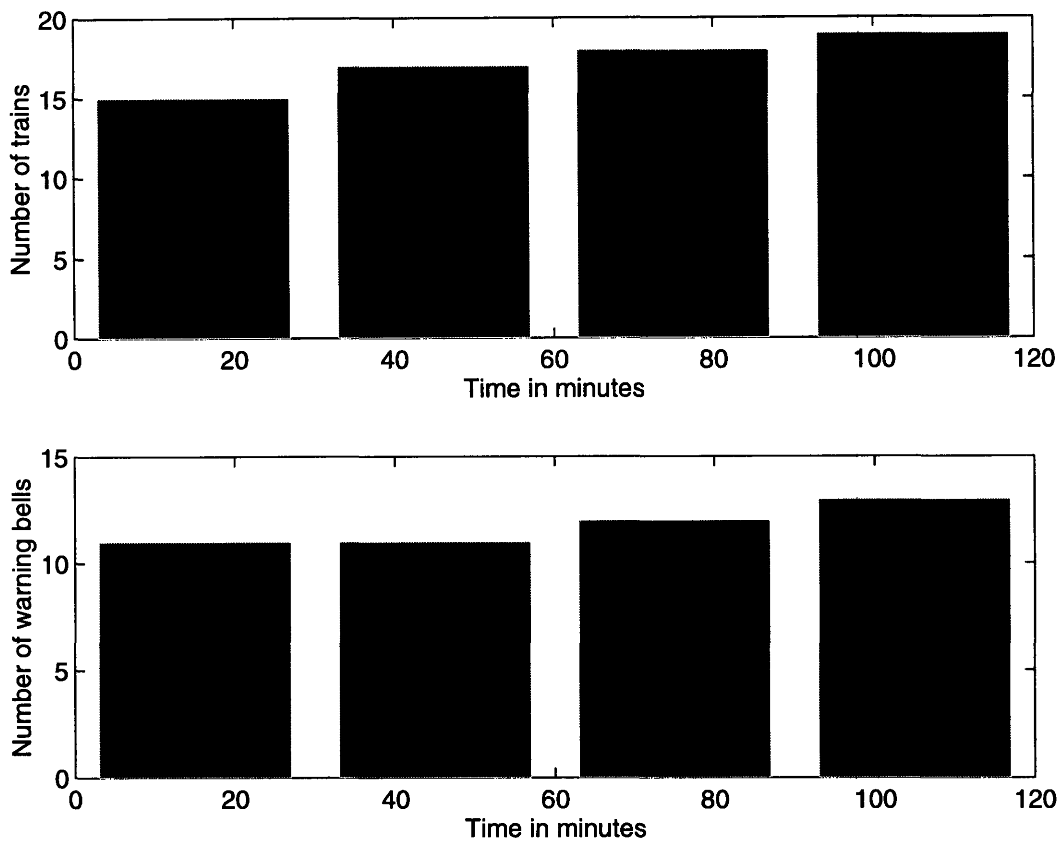


Figure 4-3: Variation by rail traffic and number of warning bells at Crossing I

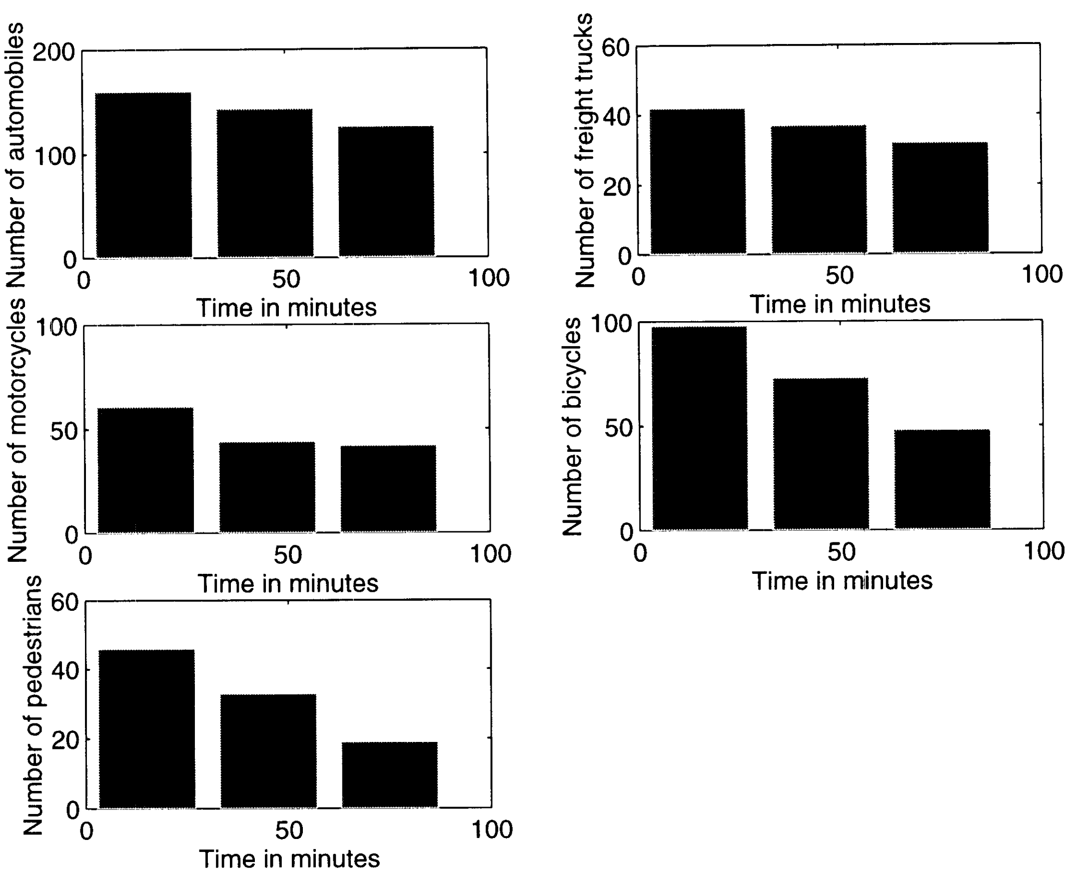


Figure 4-4: Variation by road traffic at Crossing II

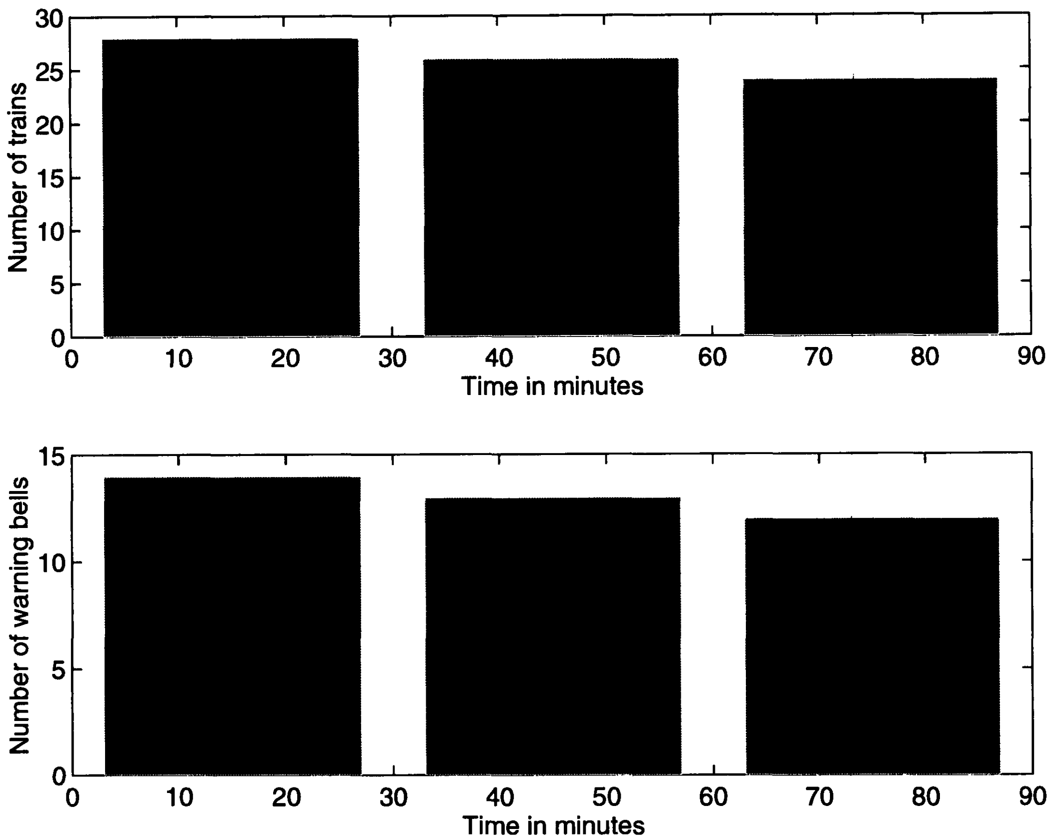


Figure 4-5: Variation by rail traffic and number of warning bells at Crossing II

Figure 4-6 shows a tree to determine the probability of the first vehicle going through the crossing as the warning bell started ringing. 60% of the first vehicles arriving at the crossing were automobiles (and they accounted for about 57% of the total traffic). 75% of the automobiles went through as the warning bell just started ringing. The chance that the first vehicle arriving at the crossing went through as the warning bell was ringing is 0.86, which in any sense is not dangerous since there is sufficient time before the barrier on the other side of the road comes down (about 9 sec) and a lot of time before the train reaches the crossing (greater than 50 sec).

An important observation was that in 12 instances, once a vehicle stopped, say a car or a freight truck, all the vehicles behind stopped and did not try to go by the side of this vehicle. But bicycles did go by, irrespective of any vehicles stopped at the crossing.

Let us now look at the likelihood that a second vehicle went through the crossing, given that either the first vehicle had gone through the crossing or the first vehicle had stopped.

i.e. $P$[Second vehicle went through the crossing] $=$ $P$[Second vehicle went through the crossing/First vehicle went through] $+$ $P$[Second vehicle went through the crossing/First vehicle stopped]

We observed that once the first vehicle had stopped, no other vehicles went by its side and into the crossing. So, we take the probability of the second term in the above equation to be zero.

Thus, the probability that we want to determine is the following:

Given that the first vehicle arriving at the crossing went through, what is the chance that the second vehicle arriving at the crossing will go through?

We model this as a probability tree of the second vehicle going through, given that the first vehicle has gone through. Figure 4-7 shows the tree for the second vehicle going through the crossing as the warning bell is ringing, given that the first vehicle has gone through. About 60% of the second vehicles coming to the crossing as the warning bell was ringing were automobiles. 53.8% of the cars went through, reducing from 77% in the previous case. Thus, some cars did stop if they were the second

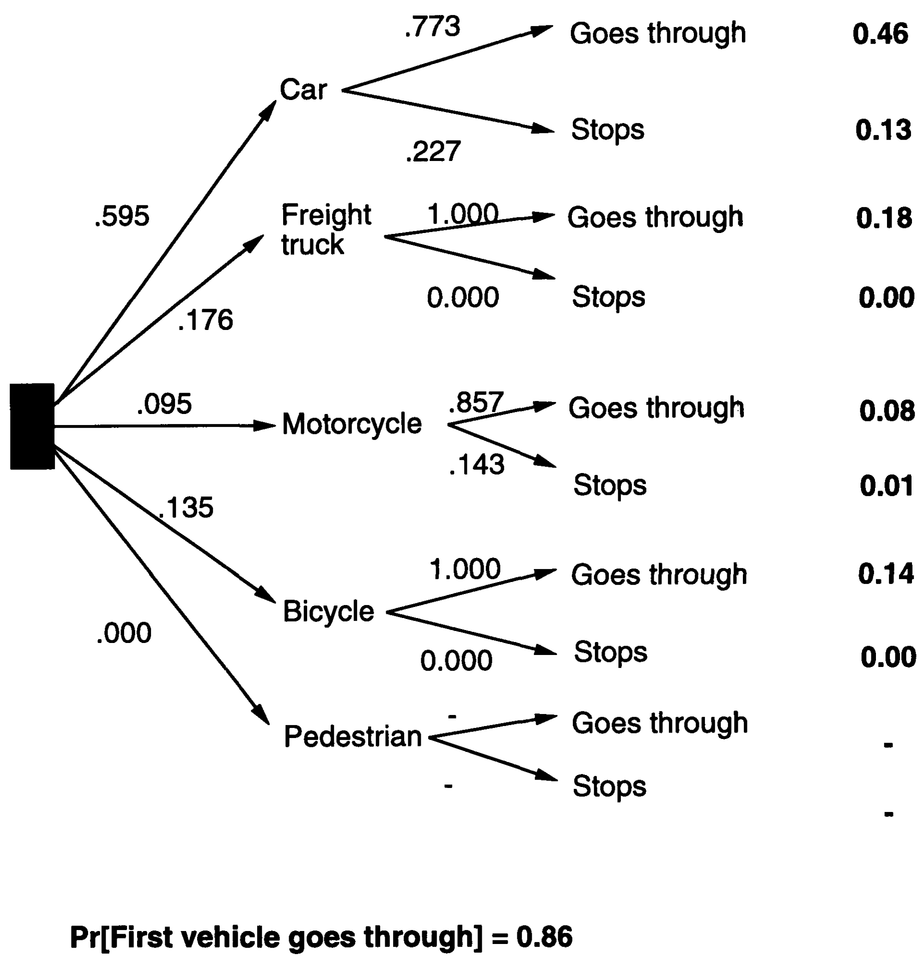


Figure 4-6: A tree to determine the chance of the first vehicle going through Crossing I as the warning bell is ringing

vehicle at the crossing (confirmed by observations). A significant number of bicycles went through (85.7%). The chance that a second vehicle went through the crossing is 0.54.

We did not model the chance of a third vehicle going through the crossing, as the

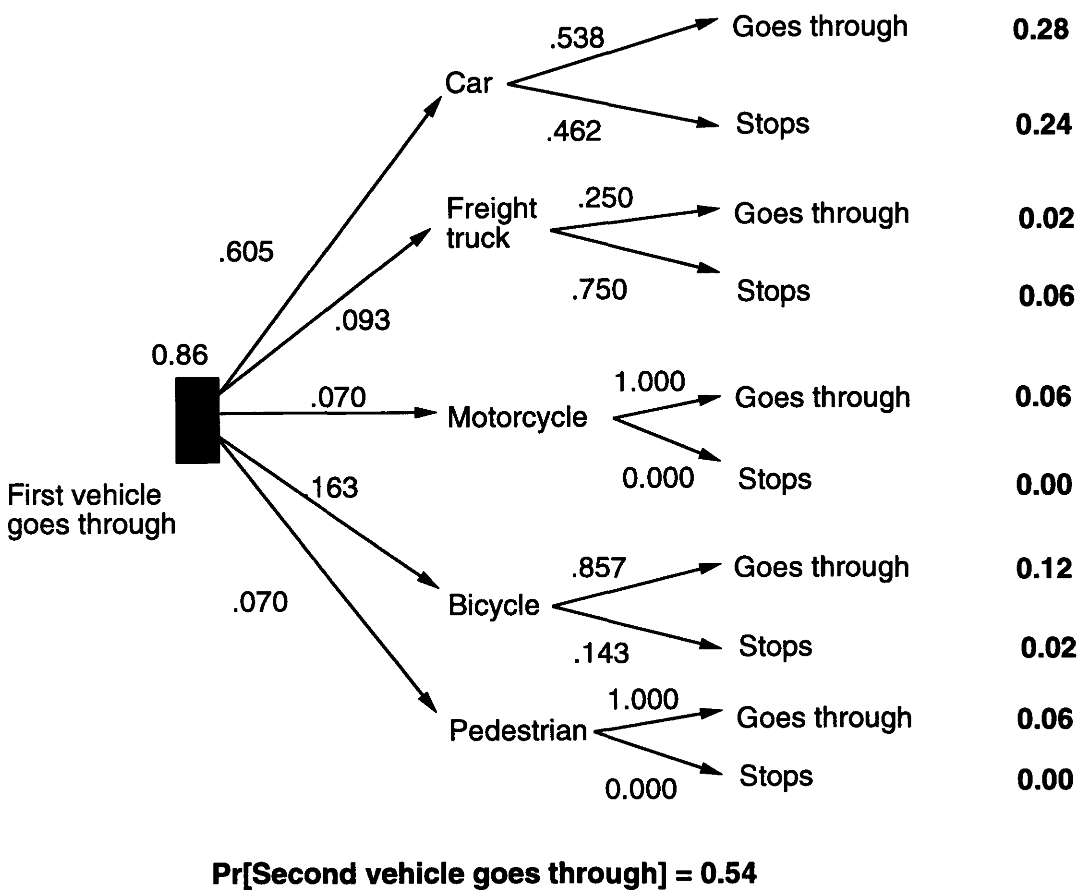


Figure 4-7: A tree to determine the chance of a second vehicle going through Crossing I as the warning bell is ringing

barrier started coming down by the time two vehicles went through the crossing (the time interval between the start of the warning bell and the descent of the barrier is 5 sec).

We will now determine the chance that a vehicle went through the crossing as the level crossing barrier started coming down. This is again conditional on whether the previous vehicle had gone through the crossing or stopped, but the probability of a vehicle going through the crossing once the barrier started coming down given that the earlier vehicle had stopped is found to be zero. The tree is shown in Figure 4-8. 47% of the vehicles arriving at the crossing were automobiles and 31% were freight trucks. More automobiles did not go through as the barrier started coming down and is confirmed from observations. The chance that a vehicle went through as the barrier started coming down is 0.30 and has significant contributions from freight trucks, bicycles and pedestrians.

We do not determine the chance of a second vehicle going through the crossing as the barrier is coming down, because of the reasons explained earlier.

No automobiles, freight trucks or motorcycles went through the crossing after the crossing barrier on the left side of the road was down. Only bicycles and a few pedestrians went through.

The following general observations can be made from the analysis:

1. After the level crossing barrier started coming down, no vehicles (cars, trucks or motorcycles) went through after 1 sec since there is not enough space for the vehicles to go through, except maybe a few bicycles.

2. A lot of vehicles went through the crossing when the level crossing warning bell stopped ringing after the train had passed, and immediately started ringing because another train was coming. One saw a melee of people and vehicles making a rush to get across as they had waited for a few minutes. This situation is dangerous, since it can lead to small vehicles like bicycles getting pushed and consequently falling on the tracks.

We construct similar probability trees for Crossing II. Figure 4-9 shows the tree for the first vehicle going through the crossing as the warning bell starts ringing. At this crossing, the chance of the first vehicle going through is 0.96. This is higher than the likelihood for Crossing I which had a chance of 0.86.

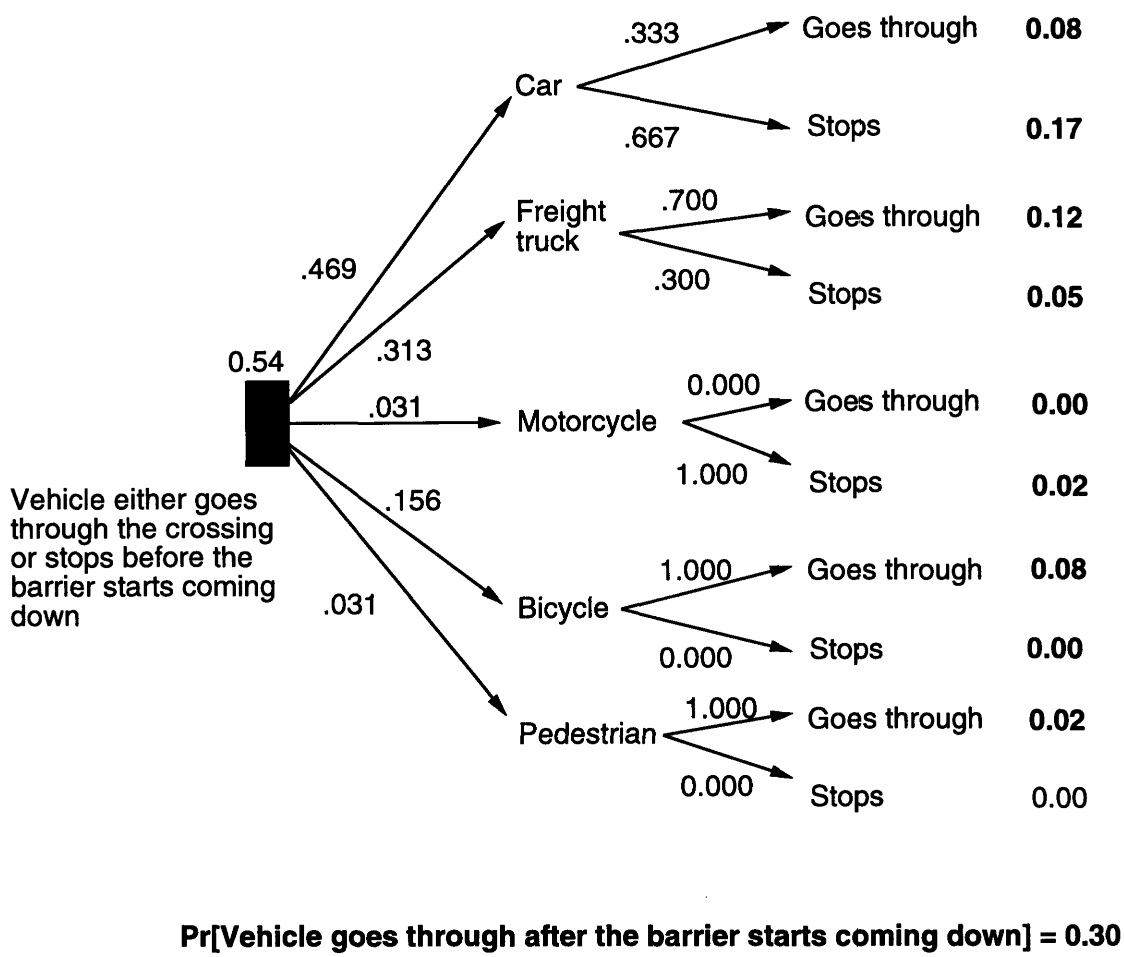


Figure 4-8: A tree to determine the chance of the first vehicle going through Crossing I as the barrier starts coming down

The chance that a second vehicle went through the crossing as the warning bell was ringing has two components:

$P$[Second vehicle went through] = $P$[Second vehicle went through/First vehicle went through] + $P$[Second vehicle went through/First vehicle stopped]

In the above expression, the probability of the second term is not zero since some bicycles went through the crossing even after the first vehicle (car or truck) had stopped (this probability is found to be 0.04). Figure 4-10 shows the chance of the second vehicle going through the crossing to be 0.69. 56% of the second vehicles arriving at the crossing were automobiles.

Here again, we do not determine the likelihood of a third vehicle going through the crossing because the barrier started coming down by the time this vehicle reached the crossing.

Figure 4-11 shows the tree for a vehicle going through the crossing as the barrier started coming down. The chance of a vehicle going through is 0.66, which is higher than that for Crossing I (which had a likelihood of 0.30). 44% of the vehicles arriving at the crossing were bicycles and all of them went through, giving the high likelihood. Again, only bicycles and pedestrians went through the crossing after the barrier on the left side of the road was down.

A comparison of the probability trees for the two crossings show that the likelihood of a vehicle going through Crossing II is higher than that at Crossing I. A plausible reasoning is as follows. Crossing II has a significant road gradient whereas Crossing I has level roads leading to the crossing. Our feeling is that the vehicles at Crossing II do not have the inclination to stop as the warning bell is ringing because they have to accelerate significantly uphill after the train goes through. They would rather go across the crossing with their current acceleration, if it was possible to do so. This suggests the importance of human factors in crossing accidents. In this particular instance, they combine with one of the level crossing attributes (road gradient) and can lead to a dangerous situation at the crossing.

Thus, a model that can incorporate the human factors of the road vehicle, in addition to the attributes of the crossing seems appropriate to contruct. We describe such a

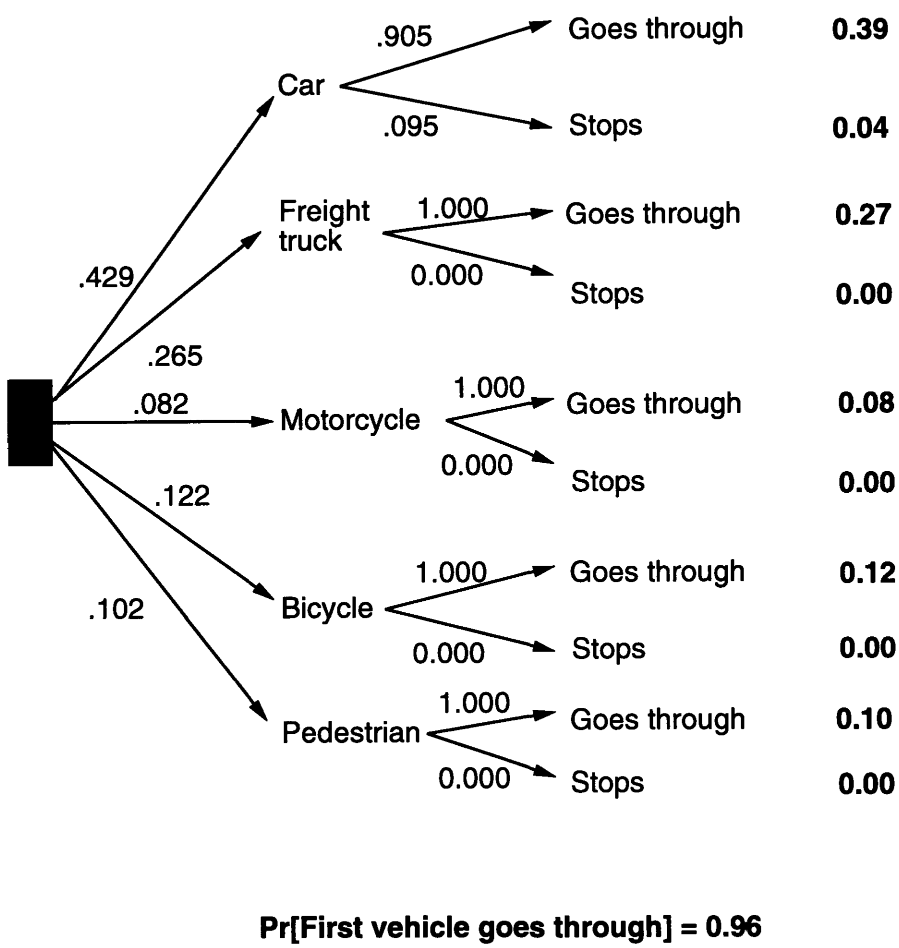


Figure 4-9: A tree to determine the chance of the first vehicle going through Crossing II as the warning bell starts ringing

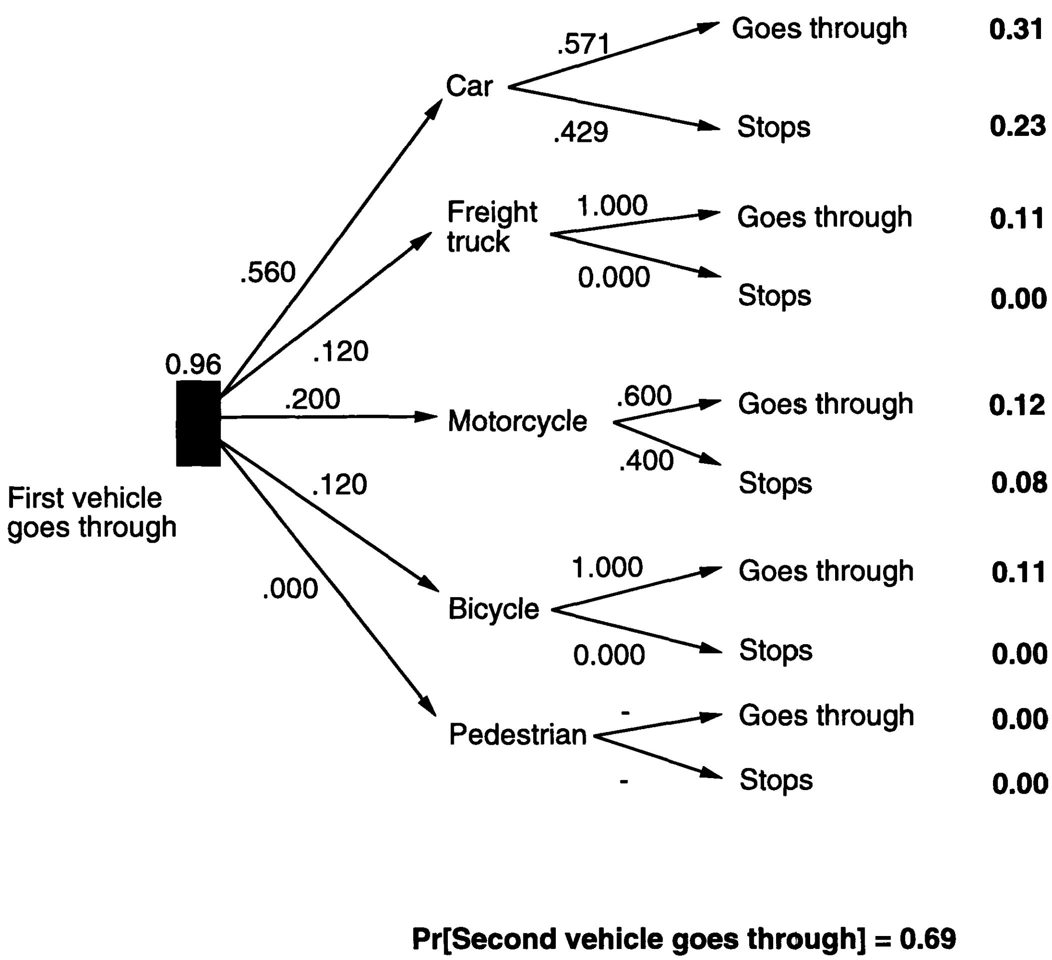


Figure 4-10: A tree to determine the chance of the second vehicle going through Crossing II as the warning bell is ringing

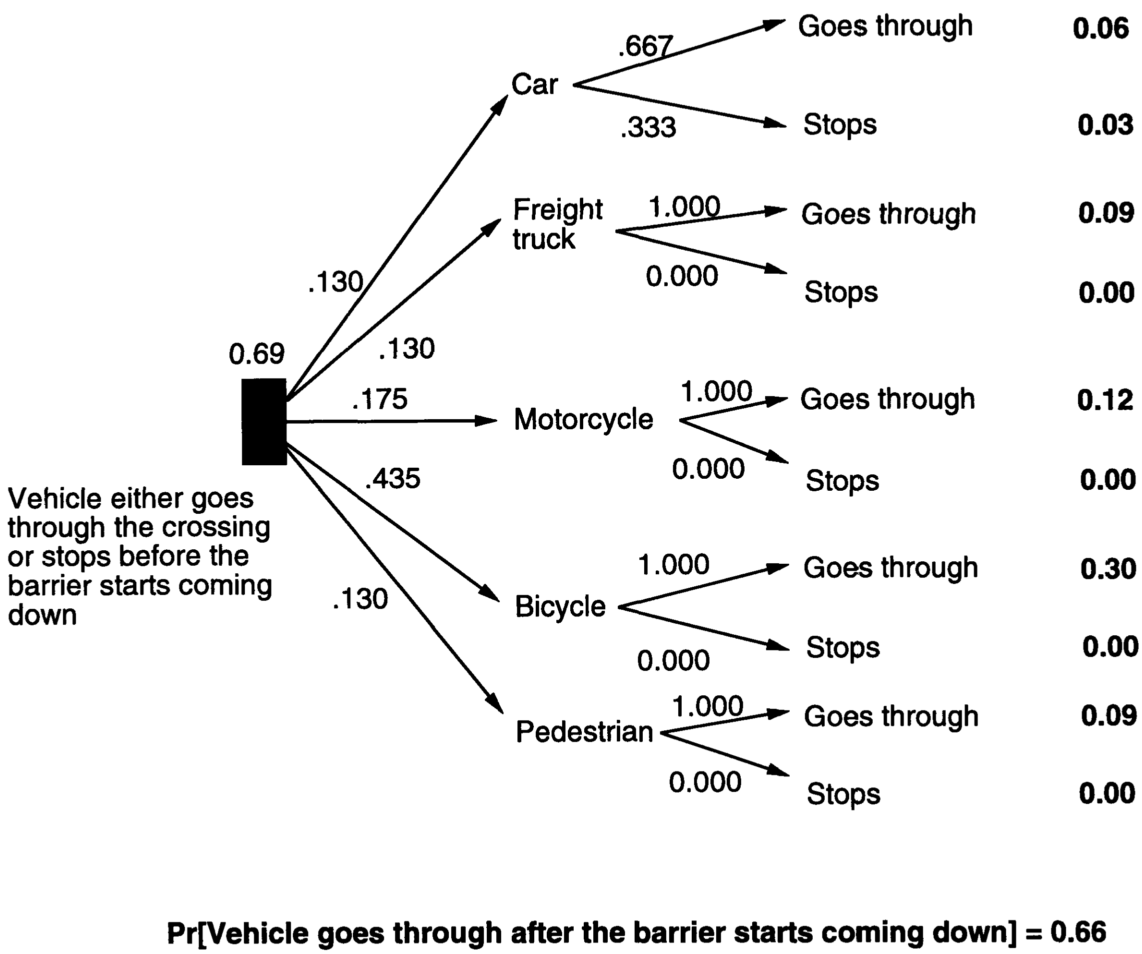


Figure 4-11: A tree to determine the chance of a vehicle going through Crossing II as the barrier starts coming down

model for the crossing accidents in the next section.

## 4.3 The Risk Model

This section describes a model to predict the safety of level crossings. It incorporates the level crossing attributes as well as the human factors involved in level crossing accidents. The framework of the model is taken from the report presented to the JR East team in October, 1995 [15].

The first parameter of the model deals with the causes of the accidents at level crossings. The accident causality analysis carried out in Section 3.4.8 shows that accidents can be broadly classified into three main categories based on their underlying characteristics.

1. Accidents caused due to intrusion: This includes accidents caused due to intrusion against the level crossing gate and clearance invasion. Here, the road vehicle tries to stop at the level crossing, but stops too close to the tracks and is hit by the train. This may happen because the vehicle is overspeeding and does not stop in time, or the vehicle does not realize the existence of the crossing or the vehicle stops correctly but it has a long projection that goes into the crossing area.

2. Accidents caused due to ignorance: Accidents due to ignorance of warning and side hit are included in this category. These accidents are caused when the road vehicle either does not see the crossing or deliberately ignores the level crossing warning and goes into the crossing and is hit by the train.

3. Accidents caused due to vehicles caught in the intersection: This category includes accidents due to wheel wreck, engine stalling and traffic congestion. The road vehicle legally enters the crossing, but is stuck because the wheels get stuck by the side of the track, or the engine stops or the vehicle is caught because of traffic congestion.

As described above, the characteristics of each type of accident is different from the other. So, a separate model is constructed for each cause.

A parameter to account for the risk involved with each type of accident is considered. We will describe this parameter in detail in the models.

The third parameter that we consider is related to the awareness of the crossing from the point of view of the road and rail traffic. Low rail traffic volume crossings are more dangerous than high rail traffic volume ones, as seen in Section 3.7.1. These awareness factors incorporate this increased risk at low train crossings.

Finally, a calibration factor ensures that the predicted number of accidents in each category is the same as the observed number of accidents.

The following sections analyze each of the accident categories in detail and determine appropriate values for the various parameters of the model.

### 4.3.1 Accidents caused due to intrusion against the crossing gate

The risk of an accident caused due to intrusion against the level crossing gate depends on the probability that a vehicle arrives during the 20 second "danger interval" and stops too close to the crossing. At very low road traffic volume crossings, the risk is low since there are possibly no vehicles during the danger interval after which the train goes past the crossing. As the road traffic increases, the risk increases since more vehicles will have to stop during the danger interval. Consider, for instance, a crossing with a traffic volume of 50 vehicles per day. Assuming that the traffic is during 20 hours of the day (i.e. there is one vehicle every 24 minutes), the probability that a vehicle will have to stop during the danger interval (assumed to be 20 seconds) is about 0.01 (0.33 divided by 24). Similarly, the probabilities can be computed for the different road traffic volumes. The parameter that characterizes the risk of accidents caused due to intrusion is referred to as the "intrusion parameter" and is summarized in Table 4.1.

The rail awareness factor is the inverse of the rail traffic volume at the crossing.

Thus, the awareness factor is more important at low rail traffic volume crossings. An awareness factor for road traffic volume is not included since vehicles did make an attempt to stop at the crossing, which is independent of road traffic volume.

| Road traffic volume | Intrusion parameter |
|---|---|
| 0-100 | 0.01 |
| 100-1000 | 0.15 |
| 1000-5000 | 0.8 |
| 5000-10000 | 1.0 |

Table 4.1: Risk parameter for accidents caused due to intrusion

### 4.3.2 Accidents caused due to ignorance of warning

The risk of an accident caused due to ignorance of warning depends on two factors:

- The probability that the vehicle headway is greater than 20 seconds (referred to as $P[Gap]$).
- The probability that a vehicle arrives during the 20 second danger interval (referred to as $P[Danger]$).

In fact, the risk is proportional to the product of the two factors mentioned above (since the two factors are independent and both of them have to happen to magnify the risk) and the resulting parameter is referred to as the "ignorance parameter".
The probability that the vehicle headway is greater than 20 seconds is very high at low road traffic volume crossings and falls as the traffic volume increases.
The probability that a vehicle arrives during the danger interval (which is 20 seconds) is very low at low road traffic volumes, and increases as the road traffic volume increases.
Table 4.2 shows the "ignorance parameter" as well as the relative contribution of the two factors to the risk of an accident due to ignorance of warning. The probability that the vehicle headway is greater than 20 seconds as a function of the road traffic

at the crossing (referred to as $P[Gap]$) can be determined using the theory of Poisson processes.

Let us assume that the arrival of vehicles at a crossing follows a Poisson process (i.e. the number of vehicles arriving at a crossing in a fixed interval of time has a Poisson distribution with rate $\lambda$). Then, the interarrival times are exponentially distributed with mean $1/\lambda$.

Consider a crossing with a road traffic volume of 0-100 vehicles per day (with a mean of 50 vehicles per day). If we assume that the traffic is during 20 hours of the day, the rate $\lambda$ is 50/20 which is 2.5 vehicles per hour.

The interarrival time of the vehicles follows an exponential distribution with mean 1/2.5. The probability density function for the distribution is given as

$$f_T(t) = \lambda e^{-\lambda t}, t \geq 0 \tag{4.1}$$

The probability that the gap between successive vehicles is greater than 20 seconds is given by

$$\begin{aligned} P[T > 20] &= \int_{20}^{\infty} \lambda e^{-\lambda t} dt && (4.2) \\ &= -[e^{-\lambda t}]_{20}^{\infty} && (4.3) \\ &= e^{-0.013} && (4.4) \\ &\approx 1 && (4.5) \end{aligned}$$

Thus, the value of $P[Gap]$ is 1 for a road traffic volume of 50 vehicles per day. Similarly, the values of $P[Gap]$ can be determined for the different road traffic volumes at the crossing.

The values for $P[Danger]$ as a function of the road traffic volume can be determined in a similar way as described in the previous section. The ignorance parameter is low for the low road traffic volume crossings, rises as the traffic volume increases (because $P[Gap]$ decreases and $P[Danger]$ increases) and finally steadies out (when $P[Gap]$

| Road traffic volume | $P[Gap]$ | $P[Danger]$ | Ignorance parameter |
|---|---|---|---|
| 0-100 | 1.0 | 0.01 | 0.01 |
| 100-1000 | 0.8 | 0.15 | 0.12 |
| 1000-5000 | 0.25 | 0.8 | 0.2 |
| 5000-10000 | 0.1 | 1.0 | 0.1 |

Table 4.2: Risk parameter for accidents caused due to ignorance of warning

becomes negligible and $P[Danger]$ approaches 1). At very high road traffic volumes, the ignorance parameter is low since a vehicle might have to stop just because there are a few vehicles ahead of it and it is highly likely that one of them will stop at the warning bell.

The rail awareness factor again varies inversely as the rail traffic volume at the crossing. At low rail traffic volume crossings, the awareness factor is high since a vehicle might not perceive the approach of a train. This is compounded if the road traffic is also low. Thus, crossings with low road and rail traffic volumes have high road and rail awareness factors. By the same token, crossings with high road traffic volume have low awareness factors, as also crossings with high rail traffic volume.

### 4.3.3 Accidents caused due to vehicles caught in the crossing

To reiterate, these accidents are caused due to wheel wreck, engine stalling and traffic congestion. The vehicles legally enter the crossing (say, when the warning bell is not ringing), but are caught in the crossing and are not able to get out in time before the train reaches the crossing.

The risk is thus directly proportional to the road traffic volume and the rail traffic volume at the crossing. As the road traffic volume increases, the likelihood of a vehicle being involved in a wheel wreck, engine stalling or traffic congestion accident increases. As the rail traffic volume increases, the available time to get the vehicle out of the crossing reduces thereby increasing the risk. Our presumption is that risk increases more than linearly with road traffic volume with the possibility of congestion at high road traffic volume crossings (given that the mean crossing is just 3.81 m from the nearest road intersection). Table 4.3 shows the risk parameter for accidents caused due to the vehicles caught in the crossing. The rail awareness factor is assumed to

| Road traffic volume | Risk parameter |
|---|---|
| 0-100 | 0.01 |
| 100-1000 | 0.1 |
| 1000-5000 | 0.6 |
| 5000-10000 | 2.5 |

Table 4.3: Risk parameter for accidents caused due to vehicles caught in the crossing

vary inversely with the rail traffic volume at the crossing, while there is no road awareness factor since the vehicles are aware of the crossing and legally enter it.

### 4.3.4 Predicting the accident rate

Once the risk parameters for the three categories of accident causes are set up, the accident rates are calculated using the following expression:

$$p_i = Cause_i \times (Aw^i_{rail}) \times (Aw^i_{road}) \times (Cal_i) \tag{4.6}$$

where

$p_i$: Accident rate for a group of crossings

$Cause_i$: Risk parameter pertaining to the different categories of accidents

$Aw^i_{rail}$: Rail awareness factor

$Aw^i_{road}$: Road awareness factor

$Cal_i$: Calibration factor

### 4.3.5 Model Runs

The model is run on two sets of data:

1. Automobile accidents at Grade 1 crossings with automatic barrier but without obstacle detector

2. Automobile accidents at Grade 1 crossings with semiautomatic automatic barrier but without obstacle detector

The details of the model runs on the two data sets are presented below.

**Test Run 1: Crossings with automatic barrier, but without obstacle detector**

Table 4.4 shows the crossings grouped on the basis of the rail and the road traffic volume at the crossing. Table 4.5 shows the observed accidents grouped on the basis of the rail and road traffic volume at the crossing. The accident exposure is calculated in Table 4.6 as the product of the rail traffic volume (the midvalue for each category of rail traffic) and the total number of crossings for the category in question.

The predicted accident rates (per million trains) for accidents caused due to

| RTV | Road traffic volume | | | |
|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| 0-20 | 79 | 112 | 46 | 5 |
| 20-40 | 339 | 378 | 166 | 27 |
| 40-60 | 176 | 175 | 55 | 16 |
| 60-80 | 157 | 142 | 48 | 6 |
| 80-100 | 58 | 61 | 22 | 3 |
| 100-120 | 98 | 86 | 25 | 3 |
| 120-160 | 45 | 80 | 28 | 2 |
| 160-200 | 18 | 44 | 33 | 2 |
| 200-400 | 32 | 28 | 21 | 6 |

Table 4.4: Run 1: Number of crossings

ignorance of warning are calculated in Table 4.7 using the equation presented in

| RTV | Road traffic volume | | | | |
|---|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 | Total |
| 0-20 | 0 | 0 | 1 | 1 | 2 |
| 20-40 | 10 | 4 | 9 | 4 | 27 |
| 40-60 | 3 | 5 | 2 | 0 | 10 |
| 60-80 | 3 | 5 | 1 | 0 | 9 |
| 80-100 | 1 | 2 | 0 | 2 | 5 |
| 100-120 | 4 | 5 | 0 | 0 | 9 |
| 120-160 | 3 | 4 | 3 | 0 | 10 |
| 160-200 | 2 | 6 | 9 | 0 | 17 |
| 200-400 | 1 | 0 | 4 | 3 | 8 |
| Total | 27 | 31 | 29 | 10 | 97 |

Table 4.5: Run 1: Number of observed accidents

| RTV | Road traffic volume | | | |
|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| 0-20 | 1.730 | 2.453 | 1.007 | 0.109 |
| 20-40 | 22.272 | 24.835 | 10.906 | 1.774 |
| 40-60 | 19.272 | 19.163 | 6.023 | 1.752 |
| 60-80 | 24.068 | 21.769 | 7.358 | 0.919 |
| 80-100 | 11.432 | 12.023 | 4.336 | 0.591 |
| 100-120 | 23.608 | 20.717 | 6.023 | 0.723 |
| 120-160 | 13.797 | 24.528 | 8.585 | 0.613 |
| 160-200 | 7.096 | 17.345 | 13.009 | 0.788 |
| 200-400 | 21.024 | 18.396 | 13.797 | 3.942 |

Table 4.6: Run 1: Accident exposure (million trains)

Section 4.3.4. The risk parameter used in the equation is as defined in Section 4.3.2. The rail awareness factors vary inversely as the square root of the rail traffic volume, decreasing by a factor of 6 from the low to the high rail traffic volume crossings. The road awareness factors decrease by a factor of 14 from the low to the high road volumes, for reasons explained in Section 4.3.2. The calibration factor of 1.75*e*-4 ensures that the predicted percentage of accidents caused due to ignorance of warning is the same as the observed percentage of accidents. The predicted accident rate (per million trains) is the highest for crossings with low rail traffic volume and medium road traffic volume. It reduces with increased rail traffic volume due to the decreasing values of the rail awareness factor. The accident rate increases for medium values of road traffic and decreases for very high traffic. The accident rate is the lowest for crossings with very high road and rail traffic volumes, due to the low values of the awareness factors and the ignorance parameter at these crossings.

Table 4.8 shows the predicted accident rate for accidents caused due to intrusion against the level crossing gate. The intrusion parameters are used from Table 4.1. The rail awareness factors are the same as explained earlier, but there is no awareness factor for the road traffic since the vehicles did try to stop at the crossing. The calibration factor is found to be 1.57*e*-6. The accident rate decreases with increased rail traffic volume, and increases with increased road traffic volume. It is the highest for crossings with very low rail traffic volume and very high road traffic volume, since more vehicles have to stop at the crossing during the "danger interval". The accident rate is the lowest for crossings with very high rail traffic volume and very low road traffic volume.

The predicted accident rate (per million trains) for accidents due to vehicles caught in the crossing is calculated in Table 4.9. The risk parameters used to calculate the accident rate are taken from Table 4.3. The rail awareness factors are the same as defined earlier. There is no road awareness factor since the vehicles legally enter the crossing. The calibration factor is found to be 5.97*e*-6. The predicted accident rate is the highest for crossings with very high road traffic.

The total predicted accident rate (per million trains) is calculated in Table 4.10 as the sum of the predicted accident rates for accidents due to ignorance of warning (Table 4.7), intrusion (Table 4.8) and caught in the crossing (Table 4.9). The total accident rate decreases with increasing rail traffic volume at the crossing and increases with increasing road traffic volume. The predicted number of accidents is obtained in Table 4.11 by multiplying the total predicted accident rates (from Table 4.10) with the accident exposure (from Table 4.6).

A test of goodness-of-fit is conducted to determine the fit of the model to the total observed number of accidents (Table 4.5). Consider the null hypothesis $H_0$ which states that the model provides a good fit to the observed accidents. The sampling distribution of this statistic is approximately $\chi^2$ [12] with 7 degrees of freedom. The value of $\chi^2$ that is obtained for the predicted number of accidents (Table 4.11) is 13.01. Since this is less than 14.07, the value of $\chi^2_{0.05}$ for 7 degrees of freedom, the null hypothesis $H_0$ cannot be rejected at the 0.05 level of significance. Thus, we conclude that the model provides a reasonably good fit to the observed number of accidents.

| RTV | Rail awareness | Road traffic volume | | | |
|---|---|---|---|---|---|
| | | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| | | Risk parameter | | | |
| | | 0.01 | 0.12 | 0.2 | 0.1 |
| | | Road awareness | | | |
| | | 0.141 | 0.043 | 0.018 | 0.012 |
| 0-20 | 0.316 | 0.078 | 0.286 | 0.199 | 0.066 |
| 20-40 | 0.183 | 0.045 | 0.165 | 0.115 | 0.038 |
| 40-60 | 0.141 | 0.035 | 0.127 | 0.089 | 0.030 |
| 60-80 | 0.120 | 0.030 | 0.109 | 0.076 | 0.025 |
| 80-100 | 0.105 | 0.026 | 0.095 | 0.066 | 0.022 |
| 100-120 | 0.100 | 0.025 | 0.090 | 0.063 | 0.021 |
| 120-160 | 0.085 | 0.021 | 0.077 | 0.054 | 0.018 |
| 160-200 | 0.075 | 0.043 | 0.068 | 0.047 | 0.016 |
| 200-400 | 0.058 | 0.014 | 0.052 | 0.037 | 0.012 |

Table 4.7: Run 1: Predicted accident rate (per million trains) for accidents due to ignorance of warning

| RTV | Rail awareness | Road traffic volume | | | |
|---|---|---|---|---|---|
| | | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| | | Risk parameter | | | |
| | | 0.01 | 0.15 | 0.8 | 1.0 |
| 0-20 | 0.316 | 0.005 | 0.074 | 0.396 | 0.495 |
| 20-40 | 0.183 | 0.003 | 0.043 | 0.230 | 0.287 |
| 40-60 | 0.141 | 0.002 | 0.033 | 0.177 | 0.221 |
| 60-80 | 0.120 | 0.002 | 0.028 | 0.151 | 0.188 |
| 80-100 | 0.105 | 0.002 | 0.025 | 0.132 | 0.165 |
| 100-120 | 0.100 | 0.002 | 0.024 | 0.125 | 0.157 |
| 120-160 | 0.085 | 0.001 | 0.020 | 0.107 | 0.133 |
| 160-200 | 0.075 | 0.001 | 0.017 | 0.094 | 0.118 |
| 200-400 | 0.058 | 0.001 | 0.014 | 0.073 | 0.091 |

Table 4.8: Run 1: Predicted accident rate (per million trains) for accidents due to intrusion

| RTV | Rail awareness | Road traffic volume | | | |
|---|---|---|---|---|---|
| | | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| | | Risk parameter | | | |
| | | 0.01 | 0.1 | 0.6 | 1.0 |
| 0-20 | 0.316 | 0.019 | 0.190 | 1.130 | 4.714 |
| 20-40 | 0.183 | 0.011 | 0.110 | 0.655 | 2.730 |
| 40-60 | 0.141 | 0.008 | 0.084 | 0.505 | 2.103 |
| 60-80 | 0.120 | 0.007 | 0.072 | 0.430 | 1.790 |
| 80-100 | 0.105 | 0.006 | 0.063 | 0.376 | 1.566 |
| 100-120 | 0.100 | 0.006 | 0.060 | 0.358 | 1.492 |
| 120-160 | 0.085 | 0.005 | 0.051 | 0.304 | 1.268 |
| 160-200 | 0.075 | 0.004 | 0.045 | 0.269 | 1.119 |
| 200-400 | 0.058 | 0.003 | 0.035 | 0.208 | 0.865 |

Table 4.9: Run 1: Predicted accident rate (per million trains) for accidents due to vehicles caught in the crossing

| RTV | Road traffic volume | | | |
|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| 0-20 | 0.102 | 0.592 | 1.730 | 5.276 |
| 20-40 | 0.059 | 0.343 | 1.000 | 3.055 |
| 40-60 | 0.045 | 0.264 | 0.771 | 2.354 |
| 60-80 | 0.039 | 0.225 | 0.656 | 2.003 |
| 80-100 | 0.034 | 0.197 | 0.574 | 1.753 |
| 100-120 | 0.032 | 0.187 | 0.546 | 1.670 |
| 120-160 | 0.027 | 0.159 | 0.465 | 1.419 |
| 160-200 | 0.049 | 0.141 | 0.410 | 1.252 |
| 200-400 | 0.019 | 0.109 | 0.317 | 0.968 |

Table 4.10: Run 1: Total predicted accident rate (per million trains)

| RTV | Road traffic volume | | | | |
|---|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 | Total |
| 0-20 | 0 | 1 | 2 | 1 | 4 |
| 20-40 | 1 | 8 | 11 | 5 | 25 |
| 40-60 | 1 | 5 | 4 | 4 | 14 |
| 60-80 | 1 | 5 | 5 | 2 | 13 |
| 80-100 | 0 | 2 | 2 | 1 | 5 |
| 100-120 | 1 | 4 | 3 | 1 | 9 |
| 120-160 | 0 | 4 | 4 | 1 | 9 |
| 160-200 | 0 | 2 | 5 | 1 | 8 |
| 200-400 | 0 | 2 | 4 | 4 | 10 |
| Total | 4 | 33 | 40 | 20 | 97 |

Table 4.11: Run 1: Total predicted accidents

**Test Run 2: Crossings with semiautomatic automatic barrier, but without obstacle detector**

A second run of the model is carried out on crossings equipped with semiautomatic automatic barrier, but without obstacle detector. Table 4.12 shows the total number of crossings grouped on the basis of the road and rail traffic volume at the crossing. Table 4.13 shows the observed accidents at the crossings. The accident exposure is calculated in Table 4.14 as the product of the rail traffic volume at the crossing and the total number of crossings in the category of interest.

Similar to Test Run 1, the predicted accident rate (per million trains) for accidents caused due to ignorance of warning are shown in Table 4.15 as the product of the ignorance parameter, the rail and road awareness factors and the calibration factor (2.4*e*-4). Again, the accident rate is the highest for crossings with low rail traffic volume and medium road traffic volume. It is the lowest for crossings with very high road and rail traffic volumes.

| RTV | Road traffic volume | | | |
|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| 0-20 | 13 | 28 | 0 | 7 |
| 20-40 | 93 | 163 | 104 | 25 |
| 40-60 | 87 | 127 | 99 | 33 |
| 60-80 | 99 | 179 | 123 | 28 |
| 80-100 | 59 | 87 | 60 | 6 |
| 100-120 | 83 | 85 | 64 | 6 |
| 120-160 | 42 | 71 | 62 | 7 |
| 160-200 | 11 | 41 | 35 | 5 |
| 200-400 | 25 | 41 | 48 | 8 |

Table 4.12: Run 2: Number of crossings

The predicted accident rate (per millon trains) for accidents caused due to intrusion are calculated in Table 4.16. The calibration factor is found to be 1.85*e*-6. As before, the accident rate is the highest for crossings with very low rail traffic volume and very high road traffic volume. It is the lowest for crossings with very high rail traffic volume and very low road traffic volume.

| RTV | Road traffic volume | | | | |
|---|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 | Total |
| 0-20 | 1 | 0 | 0 | 0 | 1 |
| 20-40 | 2 | 4 | 4 | 0 | 10 |
| 40-60 | 1 | 8 | 5 | 0 | 14 |
| 60-80 | 0 | 5 | 10 | 4 | 19 |
| 80-100 | 1 | 7 | 4 | 0 | 12 |
| 100-120 | 5 | 4 | 6 | 2 | 17 |
| 120-160 | 1 | 5 | 6 | 1 | 13 |
| 160-200 | 0 | 1 | 5 | 1 | 7 |
| 200-400 | 2 | 7 | 5 | 2 | 16 |
| Total | 13 | 41 | 45 | 10 | 109 |

Table 4.13: Run 2: Number of observed accidents

| RTV | Road traffic volume | | | |
|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| 0-20 | 0.285 | 0.613 | 0 | 0.153 |
| 20-40 | 6.110 | 10.709 | 6.833 | 1.643 |
| 40-60 | 9.527 | 13.907 | 10.841 | 3.614 |
| 60-80 | 15.177 | 27.441 | 18.856 | 4.292 |
| 80-100 | 11.629 | 17.148 | 11.826 | 1.183 |
| 100-120 | 19.995 | 20.477 | 15.418 | 1.445 |
| 120-160 | 12.877 | 21.769 | 19.009 | 2.146 |
| 160-200 | 4.336 | 16.162 | 13.797 | 1.971 |
| 200-400 | 16.425 | 26.937 | 31.536 | 5.256 |

Table 4.14: Run 2: Accident exposure (per million trains)

Table 4.17 shows the predicted accident rate for accidents due to vehicles caught in the crossing. The calibration factor is found to be 4.14*e*-6.

The total predicted accident rate (per million trains) is shown in Table 4.18 and the total number of predicted accidents are calculated in Table 4.19 by multiplying the total predicted accident rate and the accident exposure (Table 4.14).

As before, a $\chi^2$ test of goodness-of-fit [12] is carried out to determine the fit of the model to the observed accidents. The value of $\chi^2$ obtained for the model is 3.37. Since this is less than 14.07, the value of $\chi^2_{0.05}$ for 7 degrees of freedom, $H_0$ cannot be rejected at the 0.05 level of significance. Thus, the model provides a good fit to the observed number of accidents.

| RTV | Rail awareness | Road traffic volume | | | |
|---|---|---|---|---|---|
| | | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| | | Risk parameter | | | |
| | | 0.01 | 0.12 | 0.2 | 0.1 |
| | | Road awareness | | | |
| | | 0.141 | 0.043 | 0.018 | 0.012 |
| 0-20 | 0.316 | 0.109 | 0.397 | 0.277 | 0.092 |
| 20-40 | 0.183 | 0.063 | 0.230 | 0.161 | 0.054 |
| 40-60 | 0.141 | 0.048 | 0.177 | 0.124 | 0.041 |
| 60-80 | 0.120 | 0.041 | 0.151 | 0.105 | 0.035 |
| 80-100 | 0.105 | 0.036 | 0.132 | 0.092 | 0.031 |
| 100-120 | 0.100 | 0.034 | 0.126 | 0.088 | 0.029 |
| 120-160 | 0.085 | 0.029 | 0.107 | 0.075 | 0.025 |
| 160-200 | 0.075 | 0.060 | 0.094 | 0.066 | 0.022 |
| 200-400 | 0.058 | 0.020 | 0.073 | 0.051 | 0.017 |

Table 4.15: Run 2: Predicted accident rate (per million trains) for accidents due to ignorance of warning

## 4.4 Summary

This section summarizes the main points of the chapter. The human factors of the road driver are found to be a very important component of level crossing accidents.

| RTV | Rail awareness | Road traffic volume | | | |
|---|---|---|---|---|---|
| | | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| | | Risk parameter | | | |
| | | 0.01 | 0.15 | 0.8 | 1.0 |
| 0-20 | 0.316 | 0.006 | 0.088 | 0.467 | 0.584 |
| 20-40 | 0.183 | 0.003 | 0.051 | 0.271 | 0.338 |
| 40-60 | 0.141 | 0.003 | 0.039 | 0.209 | 0.261 |
| 60-80 | 0.120 | 0.002 | 0.033 | 0.177 | 0.222 |
| 80-100 | 0.105 | 0.002 | 0.029 | 0.155 | 0.194 |
| 100-120 | 0.100 | 0.002 | 0.028 | 0.148 | 0.185 |
| 120-160 | 0.085 | 0.002 | 0.024 | 0.126 | 0.157 |
| 160-200 | 0.075 | 0.001 | 0.021 | 0.111 | 0.139 |
| 200-400 | 0.058 | 0.001 | 0.016 | 0.086 | 0.107 |

Table 4.16: Run 2: Predicted accident rate (per million trains) for accidents due to intrusion

| RTV | Rail awareness | Road traffic volume | | | |
|---|---|---|---|---|---|
| | | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| | | Risk parameter | | | |
| | | 0.01 | 0.1 | 0.6 | 1.0 |
| 0-20 | 0.316 | 0.010 | 0.101 | 0.604 | 2.515 |
| 20-40 | 0.183 | 0.006 | 0.058 | 0.350 | 1.456 |
| 40-60 | 0.141 | 0.005 | 0.045 | 0.269 | 1.122 |
| 60-80 | 0.120 | 0.004 | 0.038 | 0.229 | 0.955 |
| 80-100 | 0.105 | 0.003 | 0.033 | 0.201 | 0.836 |
| 100-120 | 0.100 | 0.003 | 0.032 | 0.191 | 0.800 |
| 120-160 | 0.085 | 0.003 | 0.027 | 0.162 | 0.678 |
| 160-200 | 0.075 | 0.002 | 0.024 | 0.143 | 0.600 |
| 200-400 | 0.058 | 0.002 | 0.019 | 0.111 | 0.462 |

Table 4.17: Run 2: Predicted accident rate (per million trains) for accidents due to vehicles caught in the crossing

| RTV | Road traffic volume | | | |
|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 |
| 0-20 | 0.124 | 0.586 | 1.350 | 3.192 |
| 20-40 | 0.072 | 0.339 | 0.781 | 1.848 |
| 40-60 | 0.056 | 0.261 | 0.602 | 1.424 |
| 60-80 | 0.047 | 0.222 | 0.512 | 1.212 |
| 80-100 | 0.041 | 0.195 | 0.448 | 1.060 |
| 100-120 | 0.039 | 0.185 | 0.427 | 1.010 |
| 120-160 | 0.034 | 0.158 | 0.363 | 0.859 |
| 160-200 | 0.064 | 0.139 | 0.320 | 0.758 |
| 200-400 | 0.023 | 0.107 | 0.247 | 0.586 |

Table 4.18: Run 2: Total predicted accident rate (per million trains)

| RTV | Road traffic volume | | | | |
|---|---|---|---|---|---|
| | 0-100 | 100-1000 | 1000-5000 | 5000-10000 | Total |
| 0-20 | 0 | 0 | 0 | 1 | 1 |
| 20-40 | 0 | 4 | 5 | 3 | 12 |
| 40-60 | 1 | 4 | 7 | 5 | 17 |
| 60-80 | 1 | 6 | 10 | 5 | 22 |
| 80-100 | 1 | 3 | 5 | 1 | 10 |
| 100-120 | 1 | 4 | 7 | 1 | 13 |
| 120-160 | 0 | 3 | 7 | 2 | 12 |
| 160-200 | 0 | 2 | 4 | 2 | 8 |
| 200-400 | 0 | 3 | 8 | 3 | 14 |
| Total | 4 | 29 | 53 | 23 | 109 |

Table 4.19: Run 2: Total predicted accidents

Accidents that are caused due to intrusion against the level crossing gate and ignorance of warning have an inherent contribution from the human factors of the driver. These are the accidents that cannot be reduced by the obstacle detector. A few level crossings are analyzed to gather valuable information about the perceived actions of the road users at the crossing. These actions relate to the way in which the vehicles behave in response to the various safety devices at the crossing (warning bell and flasher and the descent of the level crossing barrier). The following conclusions can be drawn from the analysis:

1. Most vehicles go through the crossing if they are the first vehicle at the crossing when the warning bell just starts ringing.

2. Fewer vehicles go through the crossing if they are the second vehicle at the crossing when the warning bell is ringing.

3. Most automobiles stop at the crossing when the level crossing barrier starts coming down. But, bicycles and pedestrians do go through the crossing, even when the barrier is coming down.

4. A few bicycles go through the crossing after the barrier on the left side of the road is down (Figure 4-1).

5. Most vehicles stopped at the crossing go through when the warning bell stops ringing after the train has passed, and immediately starts ringing because another train is approaching the crossing.

6. The interaction between the level crossing attributes and the human factors of the road driver is a crucial component of level crossing accidents.

A model that captures this interaction between the crossing attributes and the human factors is presented. It considers four factors:

1. Causality parameter: This parameter captures the human factors of the road user for three main categories of accidents: intrusion, ignorance and caught in the crossing. The underlying human factors in each type of accident is different

from the other and is captured by a "risk parameter" defined for each of the three accident causes.

2. Rail awareness factor: This parameter accounts for the awareness of the crossing from the point of view of the rail traffic at the crossing.

3. Road awareness factor: This parameter considers the awareness of the crossing as seen from the road vehicle. Low road traffic volume crossings have a higher awareness factor compared to high road traffic volume crossings.

4. Calibration factor: This parameter is used to calibrate the model.

The details of the model runs are presented in Section 4.3. The results show that the model provides a very good prediction of the observed accidents (as shown by the $\chi^2$ test of goodness-of-fit).

Though we have run the model for automobile accidents at Grade 1 crossings without obstacle detectors (the largest category of accidents), it can also be run on the other categories of accidents by type of road traffic. The performance of the model for a set of values of the "risk parameter" can also be tried out.

# Chapter 5

# Risk Management of Level Crossings

## 5.1 Limited resources for safety

In Section 2.5, we touched upon the notion that there are always limited resources available for spending on safety. There is no doubt that safety is one of the main concerns of modern societies, but resources need to be allocated for other public services as well. Thus, the question that is posed is the following: given the limited amount of resources available for safety, how should the allocation be carried out such that we achieve the maximum possible benefit? In the context of level crossing safety, the benefit can be interpreted as the reduction in the monetary collective risk $R_m$ with a finite investment in safety measures.

## 5.2 The Methodology

We use a simple benefit-cost approach to determine the allocation of resources for risk reduction. This approach is equivalent to the marginal cost criterion that we derived in Section 2.5 as the condition for the optimal investment in safety. The procedure for the optimal allocation is as follows:

1. Determine the accident rate (per year) for each attribute of the level crossing.

2. Find the incremental reduction in accident rate (per year) $\Delta p$ in going to a higher level of safety.

3. Find the incremental cost (million yen per year) $\Delta c$ incurred in upgrading to the next level of safety.

4. Find the ratio of the incremental reduction in accident rate to the incremental cost of the safety measure $\Delta p/\Delta c$.

5. Multiply this ratio by the expected consequences (million yen) of an accident. This gives the incremental reduction in the monetary collective risk (million yen per year) to the incremental cost of the safety measure (million yen per year) $\Delta R_m/\Delta c$.

6. If $\Delta R_m/\Delta c$ is greater than 1, the application of that safety measure is justified since it results in a greater reduction in risk than its installation cost.

The methodology was developed by Carl Martland and presented to the JR East team in October, 1995 [15]. It is now applied to different attributes of the crossing and the efficacy of the various safety measures are discussed. The analysis is then extended to the development of a Risk Management Plan for level crossing safety. Finally, a set of suggestions are presented to JR East.

## 5.3 Application to level crossing attributes

The methodology discussed in the previous section is applied to the following attributes of the crossings:

1. Type of safety device

   - Grade 4 crossing, with neither a warning system nor a barrier
   - Grade 3 crossing, with a warning system but no barrier

- Grade 1 crossing, with a warning system and barrier
- Grade 1 crossing with obstacle detector
- Grade separated crossing

2. Crossings by visibility of the crossing

3. Crossings by road gradient of the crossing

The initial and annual costs of the various attributes are indicated in Table 5.1. The initial estimates were provided by the Safety Research Laboratory of JR East. We assume the equivalent uniform annual cost of a safety device to be 10% of its total cost and the maintenance cost to be 5% of the total cost to calculate the total annual cost of a safety device (assuming its life is 20 years). The following legends are used in the analyses shown below:

- G4: Grade 4 crossing
- G3: Grade 3 crossing
- G1: Grade 1 crossing
- G1+O.d: Grade 1 crossing equipped with an obstacle detector
- G.s: Grade separated crossing

| Upgrade | Initial cost (million yen) | Annual cost (million yen) |
|---|---|---|
| G4 → G3 | 11 | 1.65 |
| G3 → G1 | 8 | 1.2 |
| G4 → G1 | <19 | <2.85 |
| Obstacle detector | 17 | 2.55 |
| Alarm button | 0.4 for 2 devices | 0.06 |
| Overhang warning device | 3.4 for 2 devices | 0.51 |
| Big barrier | 0.2 for 2 barriers | 0.03 |
| Grade separation | 100 | 10 |

Table 5.1: Costs of the various safety upgrades

The accident rate (per million trains) by the rail traffic volume at the crossing is shown in Table 5.2 [15]. The expected consequences per accident $w$ is shown in Table 5.3 as a function of the rail traffic volume.

| RTV | G.s | G1+O.d | G1 | G3 | G4 |
|---|---|---|---|---|---|
| 10 | 0 | 1.240 | 1.810 | 3.620 | 7.240 |
| 30 | 0 | 0.790 | 1.780 | 3.560 | 7.120 |
| 50 | 0 | 0.670 | 1.960 | 3.920 | 7.840 |
| 70 | 0 | 0.610 | 2.140 | 4.280 | 8.560 |
| 90 | 0 | 0.580 | 2.310 | 4.620 | 9.240 |
| 110 | 0 | 0.570 | 2.480 | 4.960 | 9.920 |
| 130 | 0 | 0.540 | 2.500 | 5.000 | 10.000 |
| 150 | 0 | 0.470 | 2.600 | 5.200 | 10.400 |
| 170 | 0 | 0.460 | 2.500 | 5.000 | 10.000 |
| 190 | 0 | 0.450 | 2.400 | 4.800 | 9.600 |
| 210 | 0 | 0.440 | 2.300 | 4.600 | 9.200 |
| 230 | 0 | 0.430 | 2.200 | 4.400 | 8.800 |
| 250 | 0 | 0.420 | 2.100 | 4.200 | 8.400 |

Table 5.2: Accident rate (per million trains) by rail traffic volume

| RTV | Automobile | Freight truck | Motorcycle | Bicycle | Pedestrian |
|---|---|---|---|---|---|
| 10 | 5 | 3 | 10 | 10 | 10 |
| 30 | 10 | 5 | 15 | 15 | 15 |
| 50 | 15 | 10 | 18 | 18 | 18 |
| 70 | 20 | 16 | 20 | 20 | 20 |
| 90 | 25 | 23 | 23 | 23 | 23 |
| 110 | 30 | 30 | 26 | 26 | 26 |
| 130 | 35 | 36 | 29 | 29 | 29 |
| 150 | 40 | 42 | 32 | 32 | 32 |
| 170 | 45 | 48 | 35 | 35 | 35 |
| 190 | 50 | 56 | 38 | 38 | 38 |
| 210 | 65 | 64 | 51 | 51 | 51 |
| 230 | 70 | 80 | 54 | 54 | 54 |
| 250 | 80 | 100 | 62 | 62 | 62 |

Table 5.3: Expected consequences per accident (million yen) by rail traffic volume

### 5.3.1 Safety devices

The benefit-cost approach is carried out to determine the efficacy of the various level crossing safety devices. The approach is illustrated for two categories of rail traffic volume.

1. Low rail traffic volume crossings (30 trains per day).

2. High rail traffic volume crossings (150 trains per day).

A comparison between the two categories of rail traffic volume is carried out in terms of the type of safety device as a function of rail traffic volume. Sensitivity analyses is performed by varying the value of life estimates discussed in Section 3.5.2.

**Low rail traffic volume crossings (30 trains per day)**

Table 5.4 shows the benefit-cost analysis for crossings having a rail traffic volume of 30 trains per day. These crossings have a low volume of road traffic going across, since a lot of these crossings are located in rural areas. The first column in the table shows

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.078 | 0.039 | 0.039 | 1.65 | 0.024 | 60 | 1.44 |
| G3 → G1 | 0.039 | 0.020 | 0.019 | 1.20 | 0.016 | 60 | 0.96 |
| G1 → G1+O.d | 0.020 | 0.009 | 0.011 | 2.55 | 0.004 | 60 | 0.26 |
| G1+O.d → G.s | 0.009 | 0.000 | 0.009 | 10 | 9.0e-4 | 60 | 0.054 |

Table 5.4: Benefit-cost analysis for low rail traffic volume crossings

the upgrade to a higher level of safety at the crossing. The second and third columns show the accident rate (per year) for the upgrades being considered (obtained from Table 5.2). These are obtained by multiplying the accident rate (per million trains) by the accident exposure as defined in Section 4.3. The fourth column shows the incremental reduction in the accident rate (per year) $\Delta p$ in moving to the higher level of safety. The fifth column shows the incremental cost (million yen per year) $\Delta c$ of the upgrade (from Table 5.1). The sixth column shows the ratio of the incremental reduction in accident rate to the incremental cost $\Delta p/\Delta c$. The seventh column shows the expected consequences per accident (million yen) $w$ for the road traffic at the crossing (Table 5.3). The expected consequences implicitly assumes a value of life equal to 100 million yen. The eighth column shows the incremental reduction in the monetary collective risk to the incremental cost $\Delta R_m/\Delta c$.

The analysis justifies the upgrade of a Grade 4 crossing to a Grade 3 crossing and a Grade 3 crossing to a Grade 1 crossing (both the upgrades have $\Delta R_m/\Delta c$ greater than 1). Earlier, we saw in Section 3.5.1 that low rail traffic volume crossings have high accident rates. The above analysis justifies this finding and advocates an increase in the level of safety at these crossings. The installation of an obstacle detector is not justified since these crossings have a low volume of road traffic and have few accidents due to vehicles caught in the crossing.

**High rail traffic volume crossings (150 trains per day)**

The benefit-cost analysis is done for crossings having a rail traffic volume of 150 trains per day. These crossings have a large amount of road traffic going through everyday. Table 5.5 shows the analysis. Here, the incremental costs $\Delta c$ of the various safety measures are the same as Table 5.4, but the incremental reduction in the accident rate (per year) $\Delta p$ is higher due to the increased accident exposure.

The upgrades of a Grade 4 crossing to a Grade 3 crossing and a Grade 3 crossing to a Grade 1 crossing are clearly justified. These crossings have a large amount of rail traffic going across every day. This calls for increased safety at these crossings, as the likelihood of accidents due to ignorance of warning and vehicles caught in the crossing increases. The installation of the obstacle detector is clearly justified at these crossings, but grade separation cannot be justified only on the basis of safety.

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.570 | 0.285 | 0.285 | 1.65 | 0.173 | 178 | 30.75 |
| G3 → G1 | 0.285 | 0.143 | 0.142 | 1.20 | 0.118 | 178 | 21.06 |
| G1 → G1+O.d | 0.143 | 0.026 | 0.117 | 2.55 | 0.046 | 178 | 8.17 |
| G1+O.d → G.s | 0.026 | 0.000 | 0.026 | 10 | 2.6e-3 | 178 | 0.46 |

Table 5.5: Benefit-cost analysis for high rail traffic volume crossings

### Sensitivity analyses

In the previous section, the benefit-cost analysis for the efficacy of the various level crossing safety devices was carried out assuming a value of life equal to 100 million yen. The value of life estimates discussed in Section 3.5.2 show considerable diffusion based on the methodology used to compute the estimate and the cultural background in different countries. Thus, it seems appropriate to test the cost-benefit approach with different estimates of the value of life. We use two additional estimates addressed in Section 3.5.2 to carry out the sensitivity analyses.

#### Analysis I: Value of life estimate of 260 million yen

The analysis is the same as shown in Table 5.4 except that the expected consequences per accident are scaled up by a value of 2.6 to reflect the increased value of life estimate. This is illustrated for both the categories of rail traffic volume mentioned earlier.

**Low rail traffic volume crossings (30 trains per day)**

Table 5.6 shows the results of the benefit-cost analysis. As before, the upgrade of a Grade 4 crossing to a Grade 3 crossing and a Grade 3 crossing to a Grade 1 crossing are clearly justified for reasons mentioned earlier. Even the higher estimate of the value of life does not justify the installation of the obstacle detector at low rail traffic volume crossings.

**High rail traffic volume crossings (150 trains per day)**

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 $\rightarrow$ G3 | 0.078 | 0.039 | 0.039 | 1.65 | 0.024 | 156 | 3.74 |
| G3 $\rightarrow$ G1 | 0.039 | 0.020 | 0.019 | 1.20 | 0.016 | 156 | 2.50 |
| G1 $\rightarrow$ G1+O.d | 0.020 | 0.009 | 0.011 | 2.55 | 0.004 | 156 | 0.62 |
| G1+O.d $\rightarrow$ G.s | 0.009 | 0.000 | 0.009 | 10 | 9.0$e$-4 | 156 | 0.14 |

Table 5.6: Analysis I: Benefit-cost analysis for low rail traffic volume crossings

Table 5.7 shows the benefit-cost analysis for crossings with a rail traffic volume of 150 trains per day. As before, the results justify the upgrade of a Grade 4 crossing to a

Grade 3 crossing, a Grade 3 crossing to a Grade 1 crossing and a Grade 1 crossing to that with a detector. The high estimate of the value of life does justify grade separation and the railroad and the city will benefit in terms of faster trains and less congestion, but a potential problem can be that the cost of grade separation may be more than 10 million yen per year (as shown in Table 5.7) at certain locations.

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.570 | 0.285 | 0.285 | 1.65 | 0.173 | 463 | 80.10 |
| G3 → G1 | 0.285 | 0.143 | 0.142 | 1.20 | 0.118 | 463 | 54.63 |
| G1 → G1+O.d | 0.143 | 0.026 | 0.117 | 2.55 | 0.046 | 463 | 21.30 |
| G1+O.d → G.s | 0.026 | 0.000 | 0.026 | 10 | 2.6*e*-3 | 463 | 1.20 |

Table 5.7: Analysis I: Benefit-cost analysis for high rail traffic volume crossings

**Analysis II: Value of life estimate of 25.6 million yen**

JR East suggests a value of life of 25.6 million yen [16]. The cost-benefit analysis is carried out for this estimate of the value of life.

**Low rail traffic volume crossings (30 trains per day)**

Table 5.8 shows the results of the analysis for crossings having a rail traffic volume of 30 trains per day. None of the upgrades are justified with this low estimate of the value of life.

**High rail traffic volume crossings (150 trains per day)**

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.078 | 0.039 | 0.039 | 1.65 | 0.024 | 15 | 0.36 |
| G3 → G1 | 0.039 | 0.020 | 0.019 | 1.20 | 0.016 | 15 | 0.24 |
| G1 → G1+O.d | 0.020 | 0.009 | 0.011 | 2.55 | 0.004 | 15 | 0.06 |
| G1+O.d → G.s | 0.009 | 0.000 | 0.009 | 10 | 9.0*e*-4 | 15 | 0.01 |

Table 5.8: Analysis II: Benefit-cost analysis for low rail traffic volume crossings

The benefit-cost analysis is carried out for crossings with a rail traffic volume of 150 trains per day and is shown in Table 5.9. Even with this lower estimate of the value of life, the upgrades of a Grade 4 crossing to a Grade 3 crossing, a Grade 3 crossing to a Grade 1 crossing and a Grade 1 crossing to that with an obstacle detector are still justified.

Thus, the sensitivity analyses show that the ratios of $\Delta R_m/\Delta c$ are sensitive to the

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.570 | 0.285 | 0.285 | 1.65 | 0.173 | 46 | 7.96 |
| G3 → G1 | 0.285 | 0.143 | 0.142 | 1.20 | 0.118 | 46 | 5.43 |
| G1 → G1+O.d | 0.143 | 0.026 | 0.117 | 2.55 | 0.046 | 46 | 2.12 |
| G1+O.d → G.s | 0.026 | 0.000 | 0.026 | 10 | 2.6e-3 | 46 | 0.12 |

Table 5.9: Analysis II: Benefit-cost analysis for high rail traffic volume crossings

different estimates of the value of life. At low rail traffic volume crossings, the values of life used by JR East do not justify the upgrades of any of the crossings. But the upgrades are justified with median and high estimates of the value of life. We again stress the preliminary nature of the value of life estimates (Section 3.5.2). JR East should update the estimates based on the current perceptions of safety in Japan and carry out the benefit-cost analyses based on these estimates.

### 5.3.2 Visibility

The benefit-cost methodology is applied to evaluate the efficacy of improving crossings with low visibility (defined as the minimum distance from which the road driver can sight the crossing). Section 3.7.1 discussed the accident rate (per million trains) as a function of visibility of the crossing and concluded that the accident rate is higher for crossings with less than 20m visibility than for crossings with greater than 20m visibility.

Low visibility crossings can be improved by installing signs by the side of the road or painting the road surface indicating that there is a crossing ahead. These are low cost measures and we presume that the cost of signage and painting for a single crossing is 50,000 yen per year.

Table 5.10 shows the benefit-cost analysis for four categories of rail traffic volume.

The first column shows the rail traffic volume at the crossing. The second and third columns show the accident rates (per year) for the upgrades being considered and are obtained from Table 3.21 by multiplying the accident rate (per million trains) by the accident exposure. The fourth column shows the incremental reduction in accident rate (per year) $\Delta p$ as the visibility of the crossing improves. The fifth column shows the incremental cost (million yen per year) $\Delta c$. The ratio $\Delta p/\Delta c$ is calculated in the sixth column. The expected consequences per accident $w$ obtained from Table 5.3 (assuming a value of life equal to 100 million yen) is shown in the seventh column. Finally, the ratio of the incremental reduction in the monetary collective risk to the cost $\Delta R_m/\Delta c$ is shown in the eighth column.

The visibility improvements are clearly justified for all categories of rail traffic volume based on the values of $\Delta R_m/\Delta c$ (greater than 1).

| RTV | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| 0-40 | 0.008 | 0.006 | 0.002 | 0.05 | 0.04 | 49 | 1.96 |
| 40-80 | 0.016 | 0.012 | 0.004 | 0.05 | 0.08 | 88 | 7.04 |
| 80-120 | 0.020 | 0.011 | 0.009 | 0.05 | 0.18 | 128 | 23.04 |
| 120-160 | 0.022 | 0.018 | 0.004 | 0.05 | 0.08 | 168 | 13.44 |

Table 5.10: Benefit-cost analysis for visibility of the crossing

### 5.3.3 Road gradient

Section 3.7.2 showed the variation in the accident rate (per million trains) with the road gradient at the crossing. Crossings with a level gradient had a lower accident rate than crossings with an upward or downward gradient, but the difference in the accident rates was not statistically significant.

Crossings with a gradient can be made safer by roughening the surface of the roads leading to the crossing. Presuming that the cost of roughening for one crossing is 50,000 yen per year, the benefit-cost analysis is carried out in Table 5.11. The values for the incremental reduction in accident rate (per year) $\Delta p$ are obtained from Table 3.23 by multiplying the incremental reduction in accident rate (per million trains) by the accident exposure. Again, the expected consequences per accident are obtained from Table 5.3.

The analysis clearly justifies the investment in improving crossings with significant road gradient leading to the crossing.

| RTV | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| 0-40 | 0.005 | 0.006 | 0.001 | 0.05 | 0.02 | 49 | 0.98 |
| 40-80 | 0.006 | 0.014 | 0.008 | 0.05 | 0.16 | 88 | 14.08 |
| 80-120 | 0.009 | 0.013 | 0.004 | 0.05 | 0.08 | 128 | 10.24 |

Table 5.11: Benefit-cost analysis for road gradient of the crossing

## 5.4 Risk Management Plan

The probabilistic risk assessment methodology has been applied to level crossing accidents on the JR East network. The risk analysis yielded the accident rate and the monetary collective risk $R_m$ for level crossings with different attributes such as visibility, road gradient and presence or absence of safety devices at the crossing. The notion of perceived risk was recognized as a key aspect of the analysis and was quantified by adding weights (risk conversion factors) to the consequences of the accidents. The cost-benefit analysis looked at the efficacy of the various level crossing safety measures in reducing the risk of crossing accidents, given the limited availability of resources. The three components of the risk assessment methodology need to be tied together into a comprehensive action plan for level crossing safety that can be referred to as the Risk Management Plan.

The Risk Management Plan is an action oriented decision making tool for level crossing safety. It allocates available resources among competing safety measures, keeping in mind the accident scenario(s) addressed by each safety measure and the organization(s) responsible for the implementation of the safety measures. A schematic diagram of the Risk Management Plan is shown in Figure 5-1. The left panel of the Plan shows the investment among competing safety measures. The right panel shows the organization(s) that are responsible for implementing each of the safety measures. The plan does not explicitly show the accident scenario(s) addressed by each of the safety measures, but a discussion of the scenarios is presented below along with the role of the various organizations.

### 5.4.1 Components of the Risk Management Plan

As mentioned in the previous section, the Risk Management Plan for level crossing safety has three main components: investment among the various safety measures, the accident scenario(s) that each safety measure addresses and the organization(s) responsible for implementing the safety measures. The interaction between the three components is complex and needs to be thoroughly understood before decisions are made for investment in level crossing safety. The competing measures are:

1. Safety measures at level crossings
    - Low cost measures
    - Medium cost measures
    - High cost measures
2. Enforcement at level crossings
3. Education and media campaigns

A brief discussion of each of the measures is presented below.

#### Level crossing safety measures

Various safety measures can be installed to reduce the risk of level crossing accidents. These range from relatively inexpensive measures like signage and painting the surface of roads to medium cost measures like installing alarm buttons and overhang warning signs to more expensive investments in level crossing barriers, obstacle detectors and grade separation.

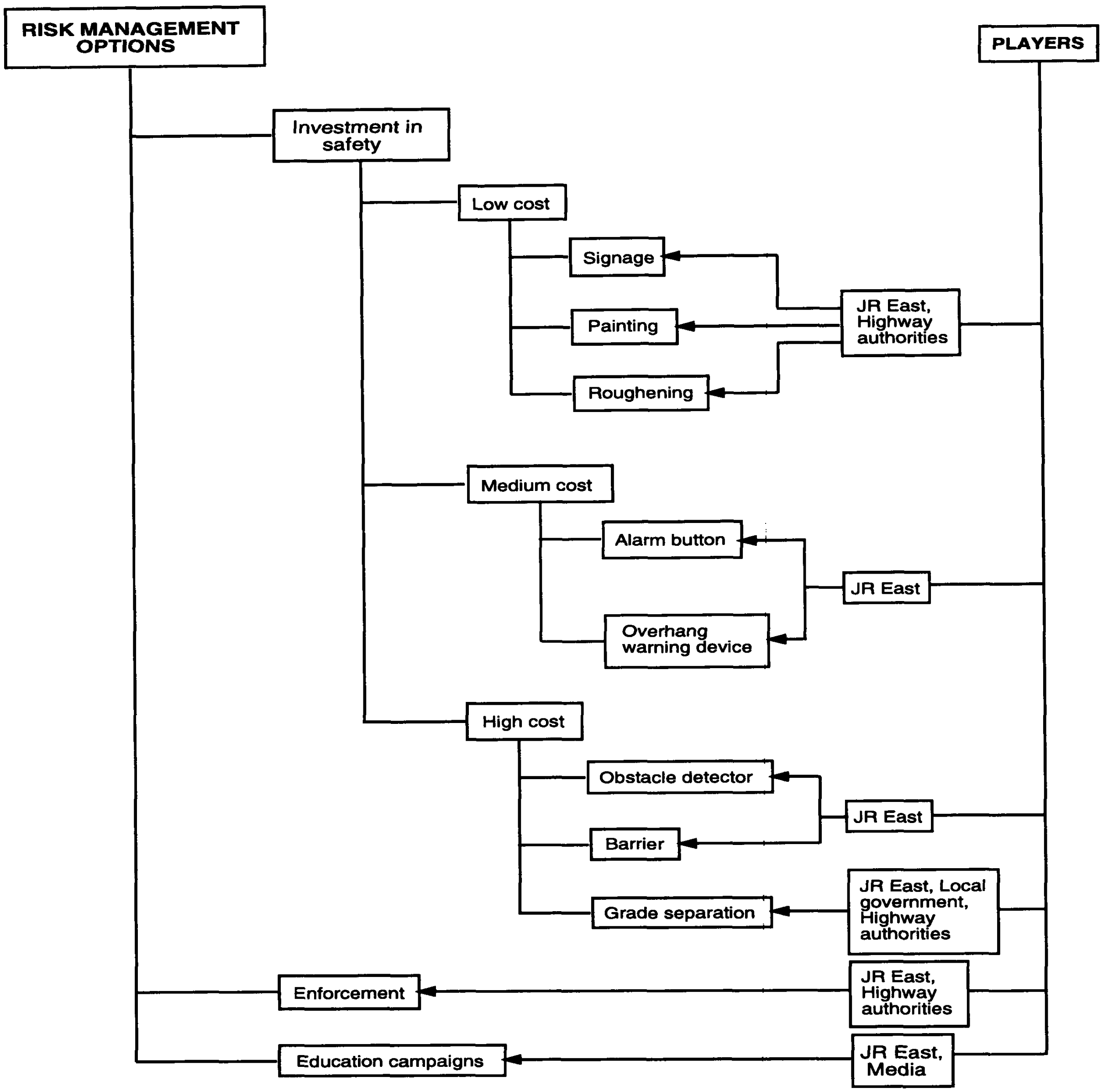


Figure 5-1: Schematic diagram of the Risk Management Plan

### Low cost measures

The low cost measures address level crossing accidents caused due to low visibility of the crossing and significant downward gradient of the road leading to the crossing (resulting in the vehicle slipping at the crossing).

Low visibility crossings can be made safer by installing signs by the side of the road indicating the presence of a crossing ahead, or the surface of the road leading to the crossing can be painted to warn the vehicle about the existence of a crossing. The signs can be made fluorescent to ensure increased visibility of the crossings during night time. The benefit-cost analysis shown in Section 5.3.2 justifies the use of these signs to improve the visibility at concerned crossings.

If crossings have a significant downward road gradient leading to the crossing, the surface of the road can be roughened to prevent slipping of the vehicle (as seen at Kuki crossing during the level crossing site visits). The benefit-cost analysis (Section 5.3.3) justifies this safety investment since the reduction in the risk is more than the cost of the safety investment.

The success of the low cost safety measures depends considerably on the cooperation between JR East and the road authorities. Any institutional barriers, if present, should be discussed and resolved so that these low cost effective measures are implemented at dangerous crossings.

### Medium cost measures

Some of the medium cost measures include the installation of alarm buttons at crossings to act as an aid to obstacle detectors and overhang warning devices at low visibility crossings and also to reduce accidents due to side hit by making the crossing more visible to the road driver.

Alarm buttons are normally installed at Grade 1 crossings equipped with obstacle detectors to act as an aid to the detector in the event of an emergency. If a vehicle is in the middle of the crossing, a third party person can operate the button which activates the railroad signalling system thereby alerting the train driver of the situation at the crossing. In some instances, the consequences of the accident can be reduced even if the train driver did not have enough time to stop the train before it reached the crossing (if the obstacle detector did not have enough time to warn the train driver and someone operated the alarm button). Even though we cannot exactly quantify the benefits of the alarm button due to the difficulty associated with isolating its efficacy with other safety devices, we believe that it has potential benefits at dangerous crossings. JR East can educate people about the operation of the alarm button in emergency situations and include it as a part of its campaign towards level crossing safety.

Overhang warning devices increase the visibility at low visibility crossings by alerting the vehicle about the existence of a crossing. They can also prevent side hit accidents by warning the unaware driver of the presence of a crossing. At present, only a few crossings have these warning devices. JR East can identify potential crossings for installing warning devices based on the risk cost criterion. These devices have potential benefits at dangerous crossings, but their installment should be justified against competing measures based on the benefit-cost criterion discussed earlier.

**High cost measures**

Upgrading crossings with barriers, installing obstacle detectors and grade separating crossings constitute the high cost safety measures at level crossings.

The analysis in Section 3.7.3 shows that Grade 1 crossings are safer than Grade 3 and Grade 4 crossings. Level crossing barriers reduce the number of illegal crossings, and hence reduce accidents due to intrusion and ignorance of warning. The probability trees constructed in Section 4.1 show that most automobiles do not attempt to go through the crossing when the barrier is coming down. But, all crossings cannot be made Grade 1 due to the limited availability of resources. Section 5.3.1 addresses the efficacy of upgrading Grade 3 and Grade 4 crossings to Grade 1 crossings as a function of rail traffic volume at the crossing and the estimates of the value of life for the consequences of the accidents. JR East should upgrade dangerous crossings based on this risk-cost criterion.

Obstacle detectors are very effective in reducing accidents due to vehicles caught in the crossing, i.e. wheel wreck, engine stalling and traffic congestion. But, they cannot be installed at all crossings. The benefit-cost analysis in Section 5.3.1 shows the potential benefits of installing a detector with respect to the rail traffic volume at the crossing. Thus, JR East should weigh the costs and benefits of installing the detector and identify potential crossings for improvement based on the risk-cost criterion.

Though grade separation is a very expensive option, it may become necessary at very high rail traffic volume crossings in urban areas. Some of the crossings in Tokyo have a high volume of rail traffic going across and it may become inevitable to grade separate to reduce the accident exposure at these crossings. JR East should carry out a cost-benefit analysis to determine whether certain crossings should be grade separated. But, it needs sustained cooperation with the highway authorities and the local government to resolve barriers to successfully implement the upgrade.

### Enforcement at level crossings

Strict enforcement by authorities is a key component of level crossing safety. Enforcement addresses illegal crossings by the road vehicle (intrusion against the crossing gate, ignorance of warning and impossible traversing). The added importance of enforcement measures comes from the fact that 53% of the level crossing accidents have resulted from intrusion and ignorance of warning (Section 3.4.8) and these accidents cannot be prevented by the obstacle detector. Enforcement by itself, though, is not very efficient since a number of level crossing accidents on the JR East network have occurred due to ignorance of warning even though a fine of 10,000 yen is levied on trespassers at crossings. Enforcement coupled with education campaigns is very effective in reducing crossing accidents, as demonstrated by Operation Lifesaver in the United States, and is discussed in the next section. The success of strict enforcement warrants the cooperation between JR East and the police to coordinate successfully in implementing stringent laws against illegal crossings.

### Education and media campaigns

Education campaigns are found to be very effective in reducing crossing accidents. Operation Lifesaver has been doing a tremendous job in the United States in educating and warning the public about the danger of illegal crossings. It coordinates its activities with enforcement officials and helps in apprehending trespassers at level crossings.

Operation Lifesaver demonstrates the potential benefits of education campaigns in reducing crossing accidents. In 1993, Operation Lifesaver received $2,500 to $50,000 in a few states in the United States [21]. The GAO report [21] highlights the success of the Operation Lifesaver program in Ohio.

"Our review of a state with an active education and enforcement program -Ohio-found that the state had reduced accidents at crossings with active warning devices from 377 in 1978 to 93 in 1993-a 75-percent decline."

"Ohio demonstrates how states with a relatively high number of accidents can successfully use education and enforcement programs to improve railroad crossing safety. Ohio's Operation Lifesaver was established in 1978 in an attempt to employ educational events and enhanced law enforcement as a means to reduce railroad crossing accidents and fatalities. The program has a full-time coordinator and 280 volunteers. Its education and enforcement efforts have helped Ohio reduce accidents at railroad crossings, especially those with active warning devices."

Thus, education campaigns are very effective in tutoring the public about the dangers of illegal crossing and are feasible from a risk-cost criterion.

JR East should advocate its education campaigns on the lines of Operation Lifesaver. The campaigns should address the following issues:

1. The company should educate the public about the causes and characteristics of the various level crossing accidents. Accidents due to illegal crossings such as intrusion against the gate and ignorance of warning should be highlighted and the dangers of such crossings discussed because these accidents cannot be prevented by the obstacle detector. The presence of signs (painting the road

surface) at low visibility crossings should be emphasized so that vehicles are not caught unaware and side hit accidents can be reduced. Accidents due to vehicles caught in the crossing such as wheel wreck, engine stalling and traffic congestion should be discussed either as media announcements or company hoardings, even though such accidents occur due to no fault of the road driver or they can be prevented by the obstacle detector. Drivers should be warned particularly against traffic congestion accidents, especially during peak periods.

2. As part of the campaigns, JR East should make known the presence of safety devices such as alarm buttons to the public and teach the use of the same. The consequences of certain accidents can be minimized by the use of the button, even though the accident cannot be prevented by the obstacle detector.
   The public should be encouraged to report malfunctions of level crossing safety equipment to the company so that they can be rectified before anything untoward happens.

3. Perhaps, the most important value of the campaigns is to inform the public about the perceived actions of the vehicles at the crossing. We believe that this is a very important component of the crossing accidents and educating the public about driving behavior will make them more conscious in the future. The following are a few points that can be highlighted in the campaigns:

   - Most vehicles stopped at the crossing go through when the level crossing warning bell stops ringing after the train goes past and immediately starts ringing as another train is approaching the crossing. This is a dangerous situation since it can result in small vehicles like bicycles and pedestrians stumbling and falling on the tracks.

   - A lot of bicycles and pedestrians go through the crossing even after the barrier on the left side of the road is down (Figure 4-1). If something untoward happens now, it increases the likelihood of an accident since there is little recovery time to get out of the crossing. Most automobiles stop at the crossing when the barrier starts coming down.

- A lot of bicycles are on the wrong side of the road when they approach the crossing. As the warning bell is ringing, they go past the right barrier but the left barrier is almost down when they reach the other side of the crossing (Figure 4-1). So, they have to go round the gate. This leads to a dangerous situation as they might get caught in the crossing, or might fall on the tracks.

- 22% of the accidents have occurred when the vehicle goes into the crossing as the bell is ringing, but has been unable to come out on the other side as something went wrong when the vehicle was in the crossing. Vehicles should stop when the warning bell starts ringing.

- Vehicles should be aware of accidents due to traffic congestion. The mean crossing is just 3.81 m from the nearest road intersection, which is less than the length of a single car (about 5 m). Vehicles should not stop on crossing tracks when waiting at a red light. This is especially important during peak hour traffic as trains arrive every few minutes at crossings.

# Chapter 6

# Conclusions

## 6.1 Summary of the thesis

This thesis analyzes level crossing accidents on JR East using the techniques of probabilistic risk assessment. The research is part of an ongoing project between MIT and JR East in the area of risk assessment. Level crossing accidents are not a common occurrence on the JR East network. A total of 927 accidents have occurred on the 7,894 crossings from April, 1987 to March, 1993. The remaining part of this section summarizes the work done in this thesis.

Chapter 1 provides an introduction to level crossing safety. The research on level crossing safety as a part of the overall risk assessment project is presented. The Safety Research Laboratory of JR East has a group which primarily works on crossing safety. They look at potential crossings that can be upgraded by installing safety devices at the crossings. They also develop computer models to simulate possible accident scenarios so that ameliorating measures can be taken before accidents occur at dangerous crossings.

A brief discussion of level crossing safety in the US is presented. Empirical techniques to predict the safety of level crossings is discussed in the context of currently used accident prediction formulas. Engineering and educational strategies to upgrade the safety of crossings is discussed.

A detailed discussion of the risk assessment methodology is presented in Chapter 2.

In general, risk is the product of the probability of occurrence of an event and its consequences, whether they be positive or negative. The risk assessment methodology poses the following two questions to determine the safety of a technical system such as a transportation system: (i) What can happen? (ii) What is acceptable? The first question refers to risk analysis which is the technical component of risk assessment and evaluates risk using techniques from engineering and probability theory. It is also important to distinguish the three notions of risk depending on the perspectives being considered: individual risk, societal risk and the company responsible for the risk. Individual risk is the probability that an individual assigns to he being involved in a risky activity. But, society is concerned about the safety of all individuals. Thus, societal risk refers to the total risk of all the individuals in the society. The company is concerned about the occurrence of catastrophic accidents which has large consequences. The second question refers to risk appraisal and involves value judgments on the part of the team conducting the risk assessment study. Society perceives risk in a way that is sometimes not conformable with reality. This relates to the issue of acceptability of risk and the way in which information about risk is communicated to society. Finally, resources need to be allocated for investments in safety. The available resources are limited so the investments should be such that the benefits outweigh the costs of the investments. The criterion for the optimum investment level is as follows:

1. Identify all the safety measures that can be applied to the system. These include both individual safety measures as well as their possible combinations.

2. Determine the cost and benefit of each safety measure (and their possible combinations).

3. The safety measures (and their possible combinations) are plotted as individual points on a risk-cost diagram (as shown in Figure 6-1).

4. The optimal risk reduction curve is drawn by connecting all the points which yield the largest reduction in risk for all possible values of the cost.

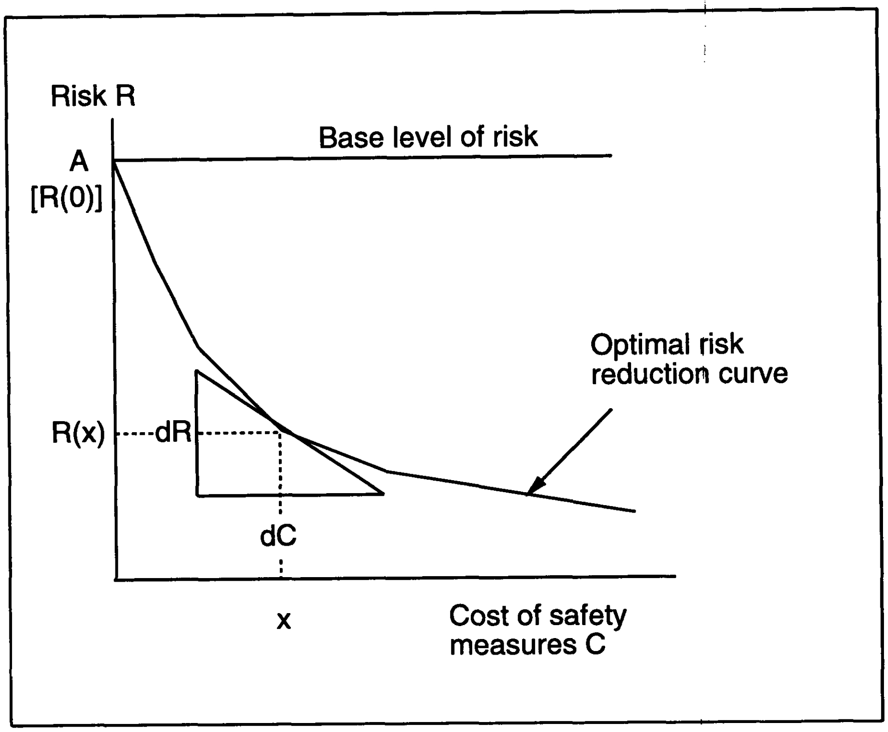


Figure 6-1: Optimal risk reduction investment

This sets the stage for analyzing the level crossing accidents on the JR East network. The analysis is based on two databases that JR East maintains with respect to level crossing safety: The Level Crossing Database and The Accident Database. The Level Crossing Database is extremely detailed in its description of the crossings and has 92 attributes for each of the crossings. Some of the important attributes are the rail traffic volume at the crossing, road traffic volume, level of safety at the crossing, visibility of the crossing from the point of view of the road driver, road gradient, location of the crossing and width of the crossing. The Level Crossing Database is listed in Appendix A. Let us now define some of the attributes of the crossings.

**Level crossing grade**: This refers to the level of safety at the crossing. There are three crossing grades:

1. Grade 1: This crossing is equipped with a warning system and level crossing barrier. The warning system consists of a warning bell and flasher. Normally,

there are 2 barriers on either side of the crossing. Figure 6-2 shows the functioning of a typical Grade 1 crossing.

2. Grade 3: This crossing is equipped only with a warning system.

3. Grade 4: This crossing has only a level crossing sign.

**Gate mechanism**: There are mainly two types of crossing barriers on the JR East network.

1. Automatic barrier: This barrier operates automatically and is connected to the train detection system. When the approaching train is detected, the barrier starts coming down and is down before the train reaches the crossing.

2. Semiautomatic-automatic barrier: These barriers are installed in station areas so that they can be operated automatically as well as manually. The manual operation is usually done by the maintenance staff under the supervision of the station master.

**Obstacle detector**: This safety device can detect the presence of any road vehicles stuck on the level crossing.

The Accident Database gives the characteristics of the accidents that have occurred at the crossings, with 57 attributes for each accident. Accident cause, type of road traffic involved in the accident and consequences (fatalities, injuries, train delays and delay hours, number of trains cancelled) are some of the important attributes of the accidents. JR East identifies seven causes of accidents at level crossings: intrusion against the level crossing gate, ignorance of warning, illegally going through a Grade 4 crossing (impossible traversing), clearance invasion, wheel wreck, engine stalling and traffic congestion. The Accident Database is given in Appendix B of the thesis. An exploratory analysis of the two databases is carried out in Section 3.3 and Section 3.4 and tries to identify the crossing attributes and their combinations that are significant to the study of the accidents. To this end, a statistical analysis which tries to ascertain the behavior of the attributes is carried out.

The risk assessment methodology is developed for the crossing accidents by defining

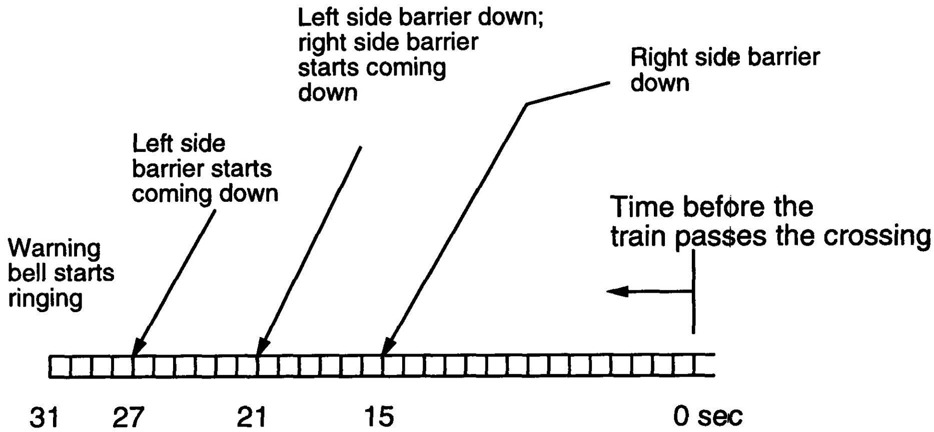


Figure 6-2: Functioning of a Grade 1 level crossing

the accident rate and the weighted average consequences per accident. The accident rate $p_i$ is defined as the number of accidents per million trains going across, and is given as

$$p_i = \frac{Acc_i}{LC_i \times (RTV) \times (365) \times (P.e)} \tag{6.1}$$

where

$Acc_i$: Number of accidents occurring due to cause $i$

$LC_i$: Number of level crossings in the concerned group

$RTV$: Rail traffic volume per day

365: 365 days per year

$P.e$: Period of exposure, in years (the period of exposure is defined as the period in which the accidents have occurred at the crossings)

Four outcomes are considered for the consequences of an accident: third party fatalities, third party injuries, train delays and train cancellations. The collective risk $R$ is defined as the product of the accident rate and the consequences per accident and summed over all accident causes. To capture the perceptions associated with catastrophic consequences, this definition of risk is extended to include the risk perception weights for different outcomes (Table 3.16 [16]) and the new definition of risk, namely, the perceived risk $R_p$ is presented. Finally, the monetary collective risk $R_m$ is defined by assigning willingness-to-pay values (on the part of JR East) for the consequences and is given by

$$R_m = \sum_{i=1}^{8} p_i \times [100 \times (fa_i) + 1 \times (in_i) + 1 \times (td_i) + 10 \times (tc_i)] \qquad (6.2)$$

where

$fa_i$: third party fatality

$in_i$: third party injury

$td_i$: train delay

$tc_i$: train cancellation

The methodology is applied to determine the accident rate $p$ and the monetary collective risk $R_m$ for crossings grouped on the basis of specific attributes. A discussion of the analysis is presented below:

**Visibility of the crossing**: Table 6.1 shows the accident rate by visibility of the crossing from the road. The accident rate (per million trains) is higher when the visibility of the crossing is lower, but it is significant only for crossings with very low visibilities (of 20m or less). The mean accident rate for crossings with visibility less than 20m is 50% higher than for crossings with greater than 20m visibility and is statistically significant.

**Road gradient**: The accident rate (per million trains) is higher as the gradient is upward or downward (Table 6.2). The mean accident rate for crossings with level road gradient is 0.43 (per million trains) and is 0.55 (per million trains) for crossings with upward or downward gradient, and the difference in the rates is statistically significant.

**Crossings by grade, but without obstacle detector**: Grade 1 crossings are safer than Grade 4 crossings, which in turn are safer than Grade 3 crossings (Fig-

| | Accident rate (per million trains) | |
|---|---|---|
| RTV | 0-20m | >20m |
| 0-40 | 1.096 | 0.828 |
| 40-80 | 0.725 | 0.537 |
| 80-120 | 0.559 | 0.309 |
| 120-160 | 0.441 | 0.361 |

Table 6.1: Accident rate by visibility of the crossing

| | Accident rate (per million trains) | |
|---|---|---|
| RTV | Level | Not level |
| 0-40 | 0.716 | 0.833 |
| 40-80 | 0.280 | 0.626 |
| 80-120 | 0.258 | 0.357 |
| 120-160 | 0.455 | 0.382 |

Table 6.2: Accident rate by road gradient

ure 6-3). The mean accident rate at Grade 1 crossings is 0.59 (per million trains), for Grade 4 crossings is 0.76 (per million trains) and is 1.25 (per million trains) for Grade 3 crossings. The mean monetary collective risk $R_m$ at Grade 1 crossings is 45 million yen (per million trains), for Grade 4 crossings is 61 million yen (per million trains) and is 103 million yen (per million trains) for Grade 3 crossings.

**Crossings by type of barrier, but without obstacle detector**: Crossings with semiautomatic-automatic barrier are slightly safer than those with automatic barrier (Figure 6-4). The mean accident rate for crossings with automatic barrier is 0.62 (per million trains) and is 0.60 (per million trains) for crossings with semiautomatic-automatic barrier, but the difference in the rates is not statistically significant. The mean risk is 50 million yen (per million trains) for crossings with automatic barrier and is 36 million yen (per million trains) for crossings with semiautomatic automatic barrier.

**Crossings with obstacle detector**: Crossings equipped with obstacle detector have a lower accident rate and risk than crossings without detector (Figure 6-5).

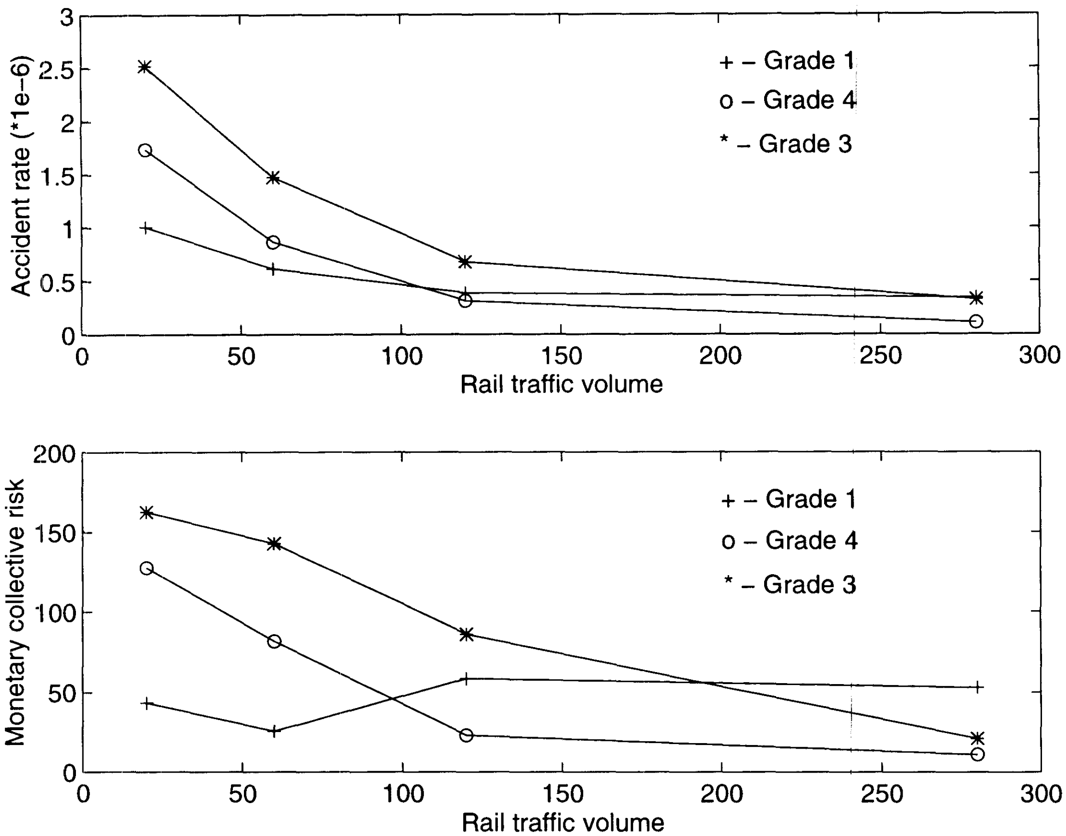


Figure 6-3: Accident rate and the monetary collective risk for crossings by grade but without obstacle detector

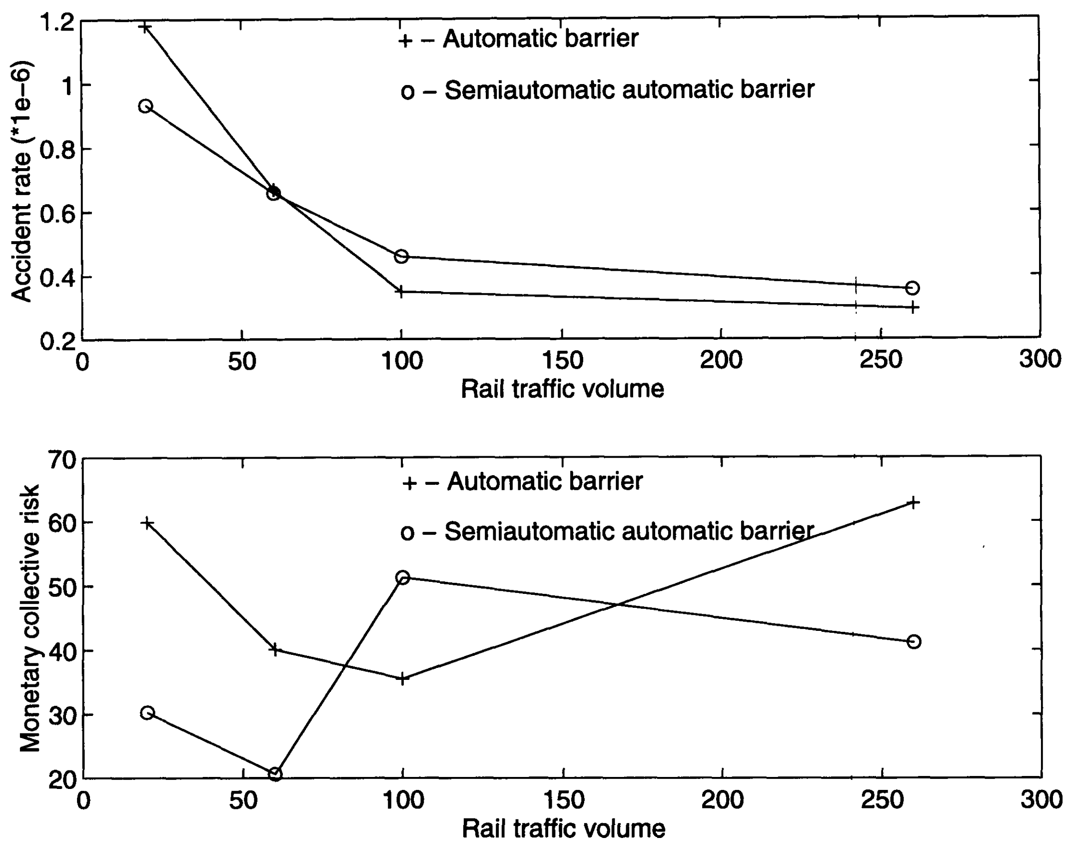


Figure 6-4: Accident rate and the monetary collective risk for crossings by type of barrier

Crossings with detectors have a mean accident rate of 0.12 (per million trains) and risk of 7 million yen (per million trains) whereas crossings without detectors have an accident rate of 0.43 (per million trains) and risk of 54 million yen (per million trains).

Catastrophic level crossing accidents are rare, yet their risk is not "zero" since they

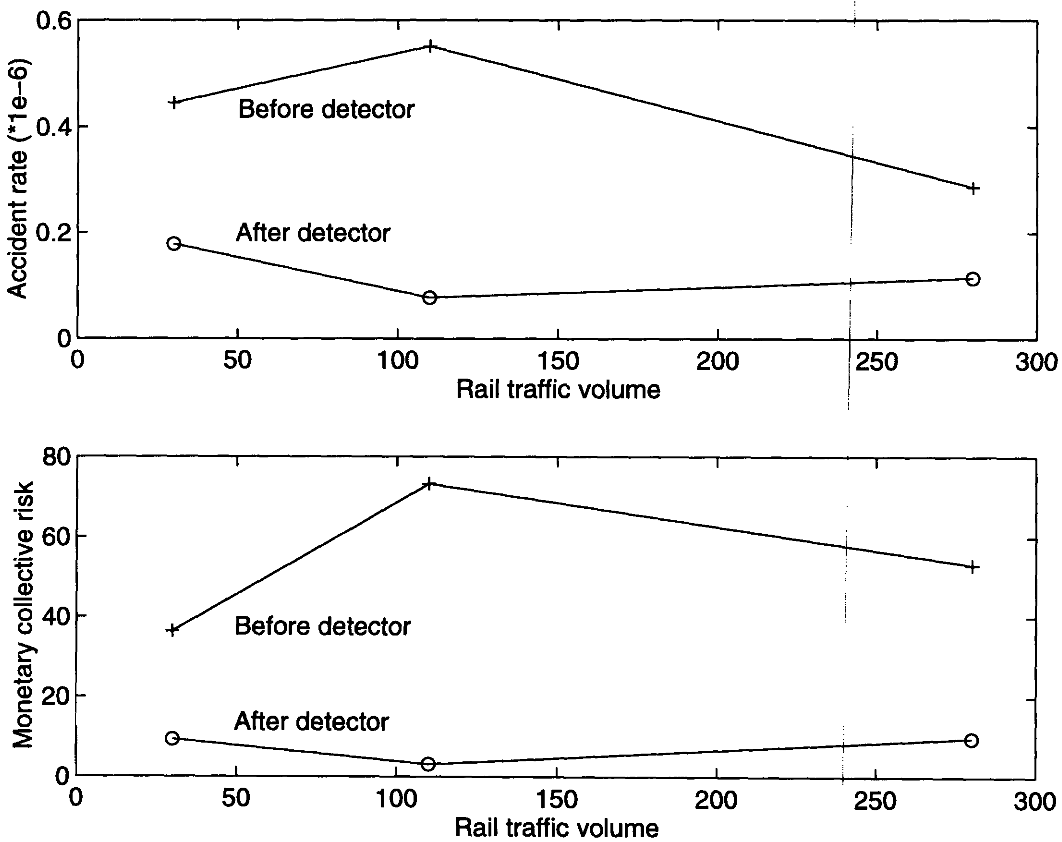


Figure 6-5: Accident rate and the collective risk for crossings with obstacle detector

have a very low probability of occurrence. To date, none of the level crossing accidents on the JR East network have involved large consequences for passengers on board the train, but a catastrophic accident is possible. Level crossing accidents with large consequences around the world have involved a train hitting a large truck or a bus and resulting in numerous casualties. This gives us an idea to estimate the risk of a catastrophic level crossing accident on the JR East network.

To determine the accident rate, we look at accidents on JR East involving a truck and a bus and calculate the rate to be 0.026 (per million trains) and 0.012 (per million trains) respectively (for a mean rail traffic of 90 trains per day).

The weighted consequences from the Global Accident Database for level crossings [2] for trucks and buses is 93 billion yen and 21 billion yen. This gives the monetary collective risk $R_m$ of a catastrophic accident involving trucks to be 2.4 billion yen and buses to be 0.24 billion yen. These values provide upper bounds to the risk of a catastrophic level crossing accident.

A perusal of the accident causes in Table 6.3 shows that more than half the accidents have occurred due to illegal crossings (ignorance of warning, intrusion against the crossing gate and illegally going through a Grade 4 crossing). This suggests that human factors are a very important component of crossing accidents. To that end, we decided to observe the perceived actions of the road users at crossings on the JR East network. This was done during my internship at JR East in the summer of 1995. I observed the behavior of the vehicles at two crossings and recorded the flow of traffic on tapes. The tapes were later analyzed at MIT. The analysis tried to answer the following questions:

1. What is the likelihood that the first vehicle arriving at the crossing goes through as the warning bell is ringing?

2. Given that the first vehicle has gone through, what is the likelihood that the second vehicle goes through the crossing as the warning bell is ringing?

3. What is the likelihood that a vehicle goes through the crossing as the barrier is coming down?

Each of the above questions was answered by constructing probability trees for both crossings to determine the likelihood of a vehicle going through. A detailed description

| Accident cause | No. of accidents | % of accidents |
|---|---|---|
| Intrusion against LC gate | 145 | 15.64 |
| Ignorance of warning | 196 | 21.14 |
| Impossible traversing | 151 | 16.29 |
| Side hit | 36 | 3.88 |
| Clearance invasion | 77 | 8.31 |
| Wheel wreck | 93 | 10.03 |
| Engine stalling | 93 | 10.03 |
| Traffic congestion | 67 | 7.23 |
| Device trouble | - | - |
| Others | 69 | 7.44 |

Table 6.3: Level crossing accidents by cause

is presented in Section 4.1. The following general conclusions can be drawn from the analysis:

1. Most vehicles go through the crossing if they are the first vehicle at the crossing when the warning bell just starts ringing.

2. Fewer vehicles go through the crossing if they are the second vehicle at the crossing when the warning bell is ringing.

3. Most automobiles stop at the crossing when the level crossing barrier starts coming down. But, bicycles and pedestrians do go through the crossing, even when the barrier is coming down.

4. A few bicycles go through the crossing after the barrier on the left side of the road is down (Figure 4-1).

5. Most vehicles stopped at the crossing go through when the warning bell stops ringing after the train has passed, and almost immediately starts ringing (2-3 seconds) because another train is approaching the crossing.

6. The interaction between the level crossing attributes and the human factors of the road driver is a crucial component of level crossing accidents.

Thus, the above discussion suggests that the interaction between the human factors and various crossing attributes is a crucial component in the study of crossing accidents. A model that captures this interaction is developed to predict level crossing accidents on the JR East network. It considers four factors:

1. Accident causality parameter: This parameter captures the human factors involved in the three categories of accidents: intrusion, ignorance and caught in the crossing. A "risk parameter" defined for each type of accident captures the underlying human factors involved in the accident.

2. Rail awareness factor: This factor accounts for the awareness of the crossing in terms of the rail traffic volume at the crossing. Low rail traffic volume crossings have a higher rail awareness factor compared to high rail traffic volume crossings.

3. Road awareness factor: This factor accounts for the awareness of the crossing from the point of view of the road traffic, with low road traffic volume crossings having a higher awareness factor than high rail traffic volume ones.

4. Calibration factor: This factor is used to calibrate the model.

The predicted accident rate $p_i$ is given by

$$p_i = Cause_i \times (Aw^i_{rail}) \times (Aw^i_{road}) \times (Cal_i) \tag{6.3}$$

where

$p_i$: Accident rate for a group of crossings

$Cause_i$: Risk parameter pertaining to the different categories of accidents

$Aw^i_{rail}$: Rail awareness factor

$Aw^i_{road}$: Road awareness factor

$Cal_i$: Calibration factor

The details of the model are presented in Section 4.3 where the significance of the various parameters are discussed and two runs of the model are shown. A goodness of fit test shows that the model predicts the observed accidents well.

As discussed in Section 5.1, there are always limited resources available for spending on safety. Thus, the resources should be allocated among competing safety measures in such a way that maximum benefit is achieved in terms of risk reduction. The competing measures are as follows:

1. Low cost measures
    - Signage at low visibility crossings
    - Painting the surface of roads at low visibility crossings
    - Roughening the surface of roads at crossings with significant downward road gradient
2. Medium cost measures
    - Installing alarm buttons
    - Installing overhanging warning devices
3. High cost measures
    - Installing level crossing barriers
    - Installing obstacle detectors
    - Grade separation
4. Enforcement
5. Education and media campaigns

We employ a benefit-cost approach to evaluate the efficacy of various risk reduction measures. This approach evaluates the benefits associated with each of the safety measures (in terms of reducing the risk) and the cost of installing the safety measure. If the benefits outweight the costs, then the installation of the safety measure is justified. This approach is applied to the following crossing attributes:

1. Type of safety device

- Grade 4 crossing, which has neither a warning system nor a barrier
- Grade 3 crossing, with a warning system but no barrier
- Grade 1 crossing, with a warning system and barrier
- Grade 1 crossing with obstacle detector
- Grade separated crossing

2. Crossings by visibility of the crossing

3. Crossings by road gradient of the crossing

Table 6.4 shows the cost of the various level crossing attributes. The initial costs were provided by the Safety Research Laboratory of JR East. The annual costs are calculated assuming that the equivalent uniform annual cost (EUAC) of a safety device is 10% of its total cost and the maintenance cost is 5% of the total cost and the life of the device is 20 years. The table uses the following legends:

- G4: Grade 4 crossing
- G3: Grade 3 crossing
- G1: Grade 1 crossing
- G1+O.d: Grade 1 crossing equipped with an obstacle detector
- G.s: Grade separated crossing

The benefit-cost analysis uses the accident rates shown in Table 6.5 [15]. The expected consequences per accident are shown in Table 6.6. The efficacy of the safety devices are discussed for two categories of rail traffic volume:

1. Low rail traffic volume crossings (30 trains per day)
2. High rail traffic volume crossings (150 trains per day)

The following analyses assume the value of life to be 100 million yen.

**Low rail traffic volume crossings**

| Upgrade | Initial cost (million yen) | Annual cost (million yen) |
|---|---|---|
| G4 → G3 | 11 | 1.65 |
| G3 → G1 | 8 | 1.2 |
| G4 → G1 | <19 | <2.85 |
| Obstacle detector | 17 | 2.55 |
| Alarm button | 0.4 for 2 devices | 0.06 |
| Overhang warning device | 3.4 for 2 devices | 0.51 |
| Big barrier | 0.2 for 2 barriers | 0.03 |
| Grade separation (G.s) | 100 | 10 |

Table 6.4: Costs of the various safety upgrades

| RTV | G.s | G1+O.d | G1 | G3 | G4 |
|---|---|---|---|---|---|
| 10 | 0 | 1.240 | 1.810 | 3.620 | 7.240 |
| 30 | 0 | 0.790 | 1.780 | 3.560 | 7.120 |
| 50 | 0 | 0.670 | 1.960 | 3.920 | 7.840 |
| 70 | 0 | 0.610 | 2.140 | 4.280 | 8.560 |
| 90 | 0 | 0.580 | 2.310 | 4.620 | 9.240 |
| 110 | 0 | 0.570 | 2.480 | 4.960 | 9.920 |
| 130 | 0 | 0.540 | 2.500 | 5.000 | 10.000 |
| 150 | 0 | 0.470 | 2.600 | 5.200 | 10.400 |
| 170 | 0 | 0.460 | 2.500 | 5.000 | 10.000 |
| 190 | 0 | 0.450 | 2.400 | 4.800 | 9.600 |
| 210 | 0 | 0.440 | 2.300 | 4.600 | 9.200 |
| 230 | 0 | 0.430 | 2.200 | 4.400 | 8.800 |
| 250 | 0 | 0.420 | 2.100 | 4.200 | 8.400 |

Table 6.5: Accident rate (per million trains) by rail traffic volume

| RTV | Automobile | Freight truck | Motorcycle | Bicycle | Pedestrian |
|---|---|---|---|---|---|
| 10 | 5 | 3 | 10 | 10 | 10 |
| 30 | 10 | 5 | 15 | 15 | 15 |
| 50 | 15 | 10 | 18 | 18 | 18 |
| 70 | 20 | 16 | 20 | 20 | 20 |
| 90 | 25 | 23 | 23 | 23 | 23 |
| 110 | 30 | 30 | 26 | 26 | 26 |
| 130 | 35 | 36 | 29 | 29 | 29 |
| 150 | 40 | 42 | 32 | 32 | 32 |
| 170 | 45 | 48 | 35 | 35 | 35 |
| 190 | 50 | 56 | 38 | 38 | 38 |
| 210 | 65 | 64 | 51 | 51 | 51 |
| 230 | 70 | 80 | 54 | 54 | 54 |
| 250 | 80 | 100 | 62 | 62 | 62 |

Table 6.6: Expected consequences per accident (million yen) by rail traffic volume

The benefit-cost analysis for crossings with a rail traffic of 30 trains per day is shown in Table 6.7. The analysis justifies the upgrades of a Grade 4 crossing to a Grade 3 crossing and a Grade 3 crossing to a Grade 1 crossing. The installation of an obstacle detector is not justified since these crossings have a low volume of rail traffic and have few accidents due to vehicles caught in the crossing.

**High rail traffic volume crossings**

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.078 | 0.039 | 0.039 | 1.65 | 0.024 | 60 | 1.44 |
| G3 → G1 | 0.039 | 0.020 | 0.019 | 1.20 | 0.016 | 60 | 0.96 |
| G1 → G1+O.d | 0.020 | 0.009 | 0.011 | 2.55 | 0.004 | 60 | 0.26 |
| G1+O.d → G.s | 0.009 | 0.000 | 0.009 | 10 | 9.0$e$-4 | 60 | 0.054 |

Table 6.7: Cost benefit analysis for low rail traffic volume crossings

Table 6.8 shows the benefit-cost analysis for crossings having a rail traffic volume of 150 trains per day. The upgrades of a Grade 4 to a Grade 3 crossing, a Grade 3 to a Grade 1 crossing and a Grade 1 crossing to that with a detector are clearly justified.

A sensitivity analysis is done by varying the estimates of the value of life. Two

| Upgrade | $p_1$ | $p_2$ | $\Delta p$ | $\Delta c$ | $\Delta p/\Delta c$ | $w$ | $\Delta R_m/\Delta c$ |
|---|---|---|---|---|---|---|---|
| G4 → G3 | 0.570 | 0.285 | 0.285 | 1.65 | 0.173 | 178 | 30.75 |
| G3 → G1 | 0.285 | 0.143 | 0.142 | 1.20 | 0.118 | 178 | 21.06 |
| G1 → G1+O.d | 0.143 | 0.026 | 0.117 | 2.55 | 0.046 | 178 | 8.17 |
| G1+O.d → G.s | 0.026 | 0.000 | 0.026 | 10 | 2.6$e$-3 | 178 | 0.46 |

Table 6.8: Cost benefit analysis for high rail traffic volume crossings

estimates are considered:

1. Value of life of 260 million yen (value used in the US)

2. Value of life of 25.6 million yen (value suggested by JR East)

The benefit-cost analyses show that the ratio $\Delta R_m/\Delta c$ is sensitive to the value of life estimates.

The three components of the risk assessment methodology discussed so far, namely, risk analysis, risk appraisal and cost-benefit analysis need to be tied together into an action plan for level crossing safety. This plan is referred to as the Risk Management Plan. The Plan allocates resources among competing safety measures, keeping in mind the accident scenario(s) addressed by each safety measure and the organization(s) responsible for the implementation of that safety measure. A detailed description of the Risk Management Plan is presented in Section 5.4. In addition to installing safety devices at crossings, the Risk Management Plan emphasizes the importance of enforcement and education campaigns in reducing crossing accidents. Thus, the Risk Management Plan acts as a guideline to JR East to determine an efficient allocation of resources for level crossing safety.

## 6.2 Conclusions

The previous section summarizes the research on level crossing safety carried out in this thesis. The main conclusions of the work are presented below:

**Factors affecting the risk of a level crossing accident**

The exploratory analysis of the crossing accidents shows that the level crossing attributes: rail traffic volume, type of road traffic at the crossing, road traffic volume, location of the crossing, visibility of the crossing from the road, road gradient, distance of the crossing to the nearest road intersection, width of the crossing (number of tracks) and the level of safety at the crossing influence the accident rate and the monetary collective risk $R_m$ of a level crossing accident.

Crossings with visibility less than 20 m have a 50% higher mean accident rate than crossings with visibility greater than 20 m, and the difference is statistically significant.

The mean accident rate for crossings with level road gradient is 0.43 (per million trains) and is 0.55 (per million trains) for crossings with upward or downward gradient.

The accident rate monotonically increases as the width of the crossing increases. As the number of tracks increase, the accident exposure increases leading to a higher accident rate.

Crossings with low rail and road traffic volume are riskier than high rail and road traffic volume crossings. The mean accident rate at crossings with a rail traffic volume of 20-40 trains per day is 0.91 (per million trains) and is 0.49 (per million trains) for crossings with a rail traffic of 140-160 trains per day. At low road traffic volume crossings, the likelihood that a vehicle will go through the crossing as the warning bell is ringing is high since there are possibly no vehicles in front of it and the risk increases if the rail traffic is low since the vehicle may not be aware of the approach of a train. The risk is lower at high road traffic volume crossings since a vehicle will have to stop just because there are vehicles in front of it at the crossing.

**Consequences of the accidents**

None of the level crossing accidents have resulted in passenger fatalities, though 10 accidents have resulted in minor passenger injuries. 197 accidents have resulted in 1 third party fatality and 8 accidents in 2 third party fatalities. 163 accidents have resulted in 1 third party injury, 16 in two injuries and 1 in more than 9 injuries. An interesting finding is that some accidents have resulted in significant train delays with a number of trains being delayed and some trains cancelled. The mean train delay is 30 minutes, though an accident on the highest train density lines can lead to hundreds of trains being delayed and cancelled. Thus, in some accidents, the consequences of train delays and cancellations are an order of magnitude higher than the consequences of fatalities and injuries. So, the definition of the monetary collective risk $R_m$ includes train delays and cancellations in addition to fatalities and injuries as the consequences of a level crossing accident.

Though the crossing accidents on the JR East network have resulted in minor consequences for the passengers on board the train, the possibility of a catastrophic accident cannot be ruled out even though it is very unlikely. A level crossing accident can become catastrophic if a train collides with a heavy vehicle like a truck and the crossing is located in an urban area. In fact, catastrophic accidents around the world have resulted from a train colliding with a truck or a bus and the worst accident in the last 15 years involved a train colliding with a heavy truck and resulted in 100 passenger fatalities and 125 total fatalities. We estimate the monetary collective risk $R_m$ of a catastrophic accident on the JR East network to be 2.4 billion yen (accident involving a train colliding with a truck). This is an upper bound on the risk of a catastrophic level crossing accident.

**Effectiveness of safety devices**

Grade 1 crossings have a lower accident rate and monetary collective risk than Grade 4 crossings, which are in turn safer than Grade 3 crossings. The mean accident rate at Grade 1 crossings is 0.59 per million trains, for Grade 3 crossings is 1.25 per million trains and is 0.76 per million trains for Grade 4 crossings.

Crossings with semiautomatic-automatic barrier are slightly safer than those equipped with automatic barrier. The mean accident rate for crossings with automatic barrier is 0.62 per million trains and is 0.60 per million trains for crossings with semiautomatic-automatic barrier.

Crossings equipped with obstacle detectors have a lower accident rate and monetary collective risk than crossings without detectors. The mean accident rate reduces from 0.43 per million trains to 0.12 per million trains after the installation of detectors.

The monetary collective risk reduces by almost a factor of 7 at crossings with detectors.

### Importance of human factors

Human factors are a very important component of crossing accidents, as half the accidents have resulted due to intrusion and ignorance of warning. An analysis of the perceived actions of the road users at crossings show the following:

1. Most vehicles go through the crossing if they are the first vehicle at the crossing when the warning bell just starts ringing.

2. Most automobiles stop at the crossing when the level crossing barrier starts coming down. But bicycles and pedestrians go through the crossing even when the barrier is coming down.

3. Most vehicles stopped at the crossing go through when the warning bell stops ringing after the train has passed, and almost immediately starts ringing (within 2-3 seconds) as another train is approaching the crossing.

4. The interaction between the level crossing attributes and the human factors of the road driver is a crucial component of level crossing accidents.

### Risk management applications

Risk management techniques can be effectively applied to allocate resources for level crossing safety. The strategies range from relatively inexpensive measures like signage and roughening the surface of roads to medium cost measures like installing alarm buttons and overhang warning devices to expensive options like upgrading crossings with barriers and obstacle detectors (the costs of the measures are shown in Table 6.4). In addition, educating the public about the dangers of illegal crossings through media announcements and publicity campaigns is an important low cost strategy. The resources for these competing strategies can be allocated using a benefit-cost criterion. The important results are shown below:

1. At low rail traffic volume crossings (30 trains per day), the upgrades of a Grade 4 crossing to a Grade 3 crossing and a Grade 3 crossing to a Grade 1 crossing

are clearly justified, whereas the installation of obstacle detectors is not justified (Table 6.7).

2. At high rail traffic volume crossings (150 trains per day), the installation of obstacle detectors is clearly justified in addition to the two upgrades mentioned above (Table 6.8).

3. The efficacy of the various safety devices is a function of the parameters used to define the monetary collective risk $R_m$. For example, the justification of the safety devices is sensitive to the estimates of the value of life used to define $R_m$.

4. Signage and painting the surface of roads to ensure increased visibility of crossings and roughening the surface of roads with significant road gradient are justified from a risk-cost criterion.

5. Finally, education and media campaigns have potential benefits in warning the public about the dangers of illegal crossings, and are feasible from a benefit-cost criterion.

## 6.3 Recommendations to JR East

The following are the general recommendations to the Safety Research Laboratory of JR East regarding level crossing safety:

1. The JR East Accident Database is comprehensive in its description of the accidents and has detailed records of all the accidents that have occurred on the network. The company should continually upgrade the Database and rectify any possible fallacies in recording entries. For example, one of the accident causes - impossible traversing was misinterpreted when information was being gathered about the accidents. Care should be taken to collect such data carefully in the future. Also, information about the accidents could be shared with the other railroads in Japan and other railroads around the world so that any unaccounted for attributes could be incorporated in the Database.

2. The risk assessment methodology described in this thesis has been applied to analyze the level crossing accidents between April, 1987 to March, 1993. JR East could easily update the analyses periodically and also account for time varying patterns in the traffic volumes at crossings. The methodology could also be applied to analyze the rich data of "near-misses". For instance, there are a number of instances of broken barriers when vehicles deliberately ignore the warning and hit the barriers. In 1993 alone, there were about 5,000 instances when barriers were broken. These events can be used to construct possible accident scenarios and extended to construct fault trees for the level crossing accidents.

3. The risk model described in Section 4.3 considers both the human factors involved in crossing accidents and the crossing attributes and predicts the accidents. The model could be run on different combinations of crossing attributes, keeping in mind the limits of statistical sufficiency.

4. Resources can be allocated for level crossing safety using the Risk Management Plan described in Section 5.4. JR East should continually examine its investment criteria among competing options and allocate resources based on the optimal risk cost criterion. Specifically, JR East should allocate resources among competing options to satisfy the following upgrades:

    - Install warning signs by the side of the road or paint the road surface at crossings with very low visibility (less than 20m).
    - Roughen the surface of roads having significant downward road gradient leading to the crossing.
    - Upgrade Grade 4 and Grade 3 crossings to Grade 1 crossings at crossings having a low volume of at least 30 trains per day, justifying the upgrades with other competing measures for safety improvement.
    - Install obstacle detectors at crossings with high rail traffic volume (150 trains per day) in urban areas, justifying the installation with other com-

peting measures.

- Install alarm buttons at crossings to act as an aid to detectors so that the consequences of certain possible accidents can be reduced, even if they cannot be prevented.
- Install overhanging warning devices at very low visibility crossings, in addition to putting up signs or painting the road surface.
- Provide big barriers (or double bar barriers) at crossings having a significant truck or bus traffic (50 vehicles per day) so that the crossing is visible. This also has implications for reducing the risk of catastrophic level crossing accidents.
- Grade separate crossings in urban areas having a high rail traffic volume, justifying its upgrade with other investments. Work with local governments and highway authorities to ease the implementation of grade separation at necessary crossings to relieve congestion and improve the safety of the network.
- Advocate education and media campaigns against illegal crossings, stressing the different types and consequences of crossing accidents and the perceived actions of the road users at crossings.

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# Appendix A

# The Level Crossing Database

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 1 | branch office | 21 | Morioka |
| | | 22 | Akita |
| | | 23 | Tohoku (Sendai) |
| | | 30 | Niigata |
| | | 41 | Takasaki |
| | | 42 | Mito |
| | | 43 | Chiba |
| | | 46 | Tokyo |
| | | 51 | Nagano |
| | | | |
| 2 | line | number | line name code |
| | | | |
| 3 | line alias | number | line alias code |
| | | | |
| 4 | track grade | 1 | grade 1 |
| | | 2 | grade 2 |
| | | 3 | grade 3 |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 4 | grade 4 |
| | | | |
| 5 | location | number | starting point station |
| | | | |
| 6 | ditto | number | terminal point station |
| | | | |
| 7 | ditto | number | distance from starting station |
| | | | |
| 8 | level crossing code | number | branch office code + level crossing code identifies each level crossing |
| | | | |
| 9 | level crossing | 1 | grade 1 |
| | grade | 3 | grade 3 |
| | | 4 | grade 4 |
| | | | |
| 10 | gate mechanism | 0 | none |
| | | 1 | automatic |
| | | 2 | semiautomatic-automatic |
| | | 3 | non-automatic |
| | | | |
| 11 | watchman | 0 | none |
| | | 1 | with watchman |
| | | | |
| 12 | traffic congestion | 0 | none |
| | | 1 | no passage of automobiles |
| | | 2 | no passage except for motorcycles, |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | | farming automobiles and light weight cars |
| | | 3 | no passage of large-sized automobiles |
| | | 4 | other regulations like one way etc. |
| | | | |
| 13 | level crossing | 1 | ordinary |
| | type | 2 | shared with other railroads |
| | | 3 | access only for employees |
| | | 4 | temporary |
| | | | |
| 14 | winter regulation | 0 | none |
| | | 1 | no passage |
| | | 2 | pedestrians only |
| | | 3 | other regulations |
| | | | |
| 15 | length | number | length of the crossing way |
| | | | |
| 16 | crossing tracks | number | number of crossing tracks |
| | | | |
| 17 | crossing direction | 0 | rectangular |
| | | 1 | left side |
| | | 2 | right side |
| | | | |
| 18 | crossing angle | number | degree of crossing angle |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 19 | track gradient | 0 | level |
| | | 1 | upward |
| | | 2 | downward |
| | | | |
| 20 | degree of gradient | number | unit: percent |
| | | | |
| 21 | track composition | 1 | one track |
| | | 2 | two tracks |
| | | 3 | three tracks |
| | | 4 | four tracks |
| | | 5 | five or more tracks |
| | | 6 | two single tracks in parallel |
| | | 7 | service track |
| | | 8 | industry track |
| | | | |
| 22 | width | number | crossing way width (in m) |
| | | | |
| 23 | ditto | number | width of the pavement |
| | | | |
| 24 | width disparity, left | | left side width disparity between the crossing way and the approaching road |
| | | 0 | none |
| | | 1 | crossing is wider |
| | | 2 | approaching road is wider |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 25 | disparity value, left | number | left side width disparity value (in m) |
| | | | |
| 26 | width disparity, right | | right side width disparity between the crossing way and the approaching road |
| | | 0 | none |
| | | 1 | crossing is wider |
| | | 2 | approaching road is wider |
| | | | |
| 27 | disparity value, right | number | right side width disparity value (in m) |
| | | | |
| 28 | pavement | 1 | concrete rigid frame |
| 29 | ditto | 2 | concrete |
| | | 3 | asphalt |
| | | 4 | wood with iron plate |
| | | 5 | wood |
| | | 6 | stone |
| | | 9 | others |
| | | | |
| 30 | visibility, left | number | visibility on the left side of the road (in m) |
| | | | |
| 31 | visibility, right | number | visibility on the right side of the road (in m) |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
| --- | --- | --- | --- |
| | | | |
| 32 | wheel protection | 0 | none |
| | | 1 | guide wall |
| | | 2 | approach slope |
| | | 3 | guide wall and approach slope |
| | | | |
| 33 | track alignment | 1 | straight |
| | | 2 | curved |
| | | | |
| 34 | radius | number | curve radius (in m) |
| | | | |
| 35 | rubber | 0 | without wheel protection rubber |
| | | 1 | with wheel protection rubber |
| | | | |
| 36 | width, left | number | gross width of left side road observed from track starting side (in m) |
| | | | |
| 37 | ditto | number | effective width for wheeled vehicle of the left side road observed from track starting side (in m) |
| | | | |
| 38 | width, right | number | gross width of the right side road observed from track starting side (in m) |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 39 | ditto | number | effective width for wheeled vehicle of the right side road observed from track starting side (in m) |
| | | | |
| 40 | road gradient, | 0 | level |
| | left | 1 | upward |
| | | 2 | downward |
| | | 9 | steps - for pedestrians only |
| | | | |
| 41 | ditto | number | left side degree of road gradient (in m) |
| | | | |
| 42 | road gradient, | 0 | level |
| | right | 1 | upward |
| | | 2 | downward |
| | | 9 | steps |
| | | | |
| 43 | ditto | number | right side degree of road gradient (in m) |
| | | | |
| 44 | road alignment, | 1 | straight |
| | left | 2 | curved |
| | | | |
| 45 | road alignment, | 1 | straight |
| | right | 2 | curved |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 46 | intersection | number | left side distance to nearby intersection (in m) |
| | | | |
| 47 | intersection | number | right side distance to nearby intersection (in m) |
| | | | |
| 48 | track perspective, left starting | number | track perspective distance (in m) |
| | | | |
| 49 | ditto, left terminal | number | from left side to track terminal side (in m) |
| | | | |
| 50 | ditto, right starting | number | from right side to track starting side (in m) |
| | | | |
| 51 | ditto, right terminal | number | from right side to track terminal side (in m) |
| | | | |
| 52 | maximum speed | number | maximum train speed (in km/h) |
| | | | |
| 53 | minimum speed | number | minimum train speed (in km/h) |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 54 | train perspective, starting | number | maximum distance from which driver can observe level crossing from track starting side (in m) |
| | | | |
| 55 | ditto, terminal | number | from track terminal side (in m) |
| | | | |
| 56 | school | 0 | without road regulation for school attendance |
| | | 1 | with road regulation for school attendance |
| | | | |
| 57 | circumstance | 1 | industrial |
| | | 2 | commercial |
| | | 3 | residential |
| | | 4 | rural |
| | | 5 | port |
| | | | |
| 58 | kindergarten, left | number | distance to nearby kindergarten or elementary school, left side (in m) |
| | | | |
| 59 | ditto, right | number | right side (in m) |
| | | | |
| 60 | magnification | number | time of road magnification (year, month) |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | | |
| 61 | rigid frame | number | time of installation of concrete rigid frame pavement (year, month) |
| | | | |
| 62 | alarm button | 0 | none |
| | | 1 | type A |
| | | 2 | type B |
| | | 3 | type C |
| | | 4 | type D |
| | | 9 | others |
| | | | |
| 63 | ditto | number | number of alarm buttons, left side |
| | | | |
| 64 | ditto | number | ditto, right side |
| | | | |
| 65 | obstruction | 0 | none |
| | detector | 1 | LED |
| | | 2 | loop coil |
| | | 3 | laser rays |
| | | 4 | photo tubes |
| | | 5 | supersonic waves |
| | | 9 | others |
| | | | |
| 66 | ditto (year) | number | year when the detector was installed |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
| --- | --- | --- | --- |
| 67 | ditto (month) | number | month of installation |
| | | | |
| 68 | direction indicator | 0 | none |
| | | 1 | with direction indicator |
| | | | |
| 69 | warning device, left | number | number of overhanging warning devices, left side |
| | | | |
| 70 | ditto, right | number | ditto, right side |
| | | | |
| 71 | gate composition | 0 | none |
| | | 1 | 1 pair of full interception |
| | | 2 | 2 pairs of full interception |
| | | 3 | 3 or more pairs of full interception |
| | | 4 | 1 pair of semi interception |
| | | 5 | 2 pairs of semi interception |
| | | 6 | 3 or more pairs of semi interception |
| | | 9 | others |
| | | | |
| 72 | interception gap | number | in m |
| | | | |
| 73 | road traffic sign | 0 | no interlocking |
| | | 1 | green in normalcy |
| | | 2 | yellow intermittent in normalcy |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 3 | yellow in normalcy |
| | | 4 | red in normalcy |
| | | 9 | other type of interlocking |
| | | | |
| 74 | warning | number | maximum warning duration for up train (in sec) |
| | | | |
| 75 | ditto | number | maximum warning duration for down train (in sec) |
| | | | |
| 76 | ditto | number | minimum warning duration for up train (in sec) |
| | | | |
| 77 | ditto | number | minimum warning duration for down train (in sec) |
| | | | |
| 78 | rail traffic | number | rail traffic volume per day |
| | volume | | |
| | | | |
| 79 | ditto | number | maximum rail traffic volume per hour |
| | | | |
| 80 | road traffic volume | number | converted road traffic volume per day |
| | | | |
| 81 | ditto | number | maximum converted road traffic |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | | volume per hour |
| | | | |
| 82 | pedestrian | number | number of passing pedestrians per day |
| | | | |
| 83 | light vehicle | number | number of light vehicles per day |
| | | | |
| 84 | motorcycle | number | number of passing motorcycles per day |
| | | | |
| 85 | automobile | number | number of passing tricycles and automobiles per day |
| | | | |
| 86 | bus | number | number of buses among the above counted automobiles |
| | | | |
| 87 | truck | number | number of trucks among the above counted automobiles |
| | | | |
| 88 | road traffic | number | road traffic volume at the time of maximum rail traffic volume |
| | | | |
| 89 | rail traffic | number | rail traffic volume at the time of maximum road traffic volume |
| | | | |
| 90 | interception | number | intercepted road traffic volume |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | | |
| 91 | ditto | number | total interception duration per day (in hour) |
| | | | |
| 92 | ditto | number | maximum interception duration per hour (in minutes) |

# Appendix B

# The Accident Database

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 1 | accident features 1 | 1 | responsible and serious accident |
| | | 2 | responsible and quasi-serious accident |
| | | A | responsible accident |
| | | 3 | responsible incident, rank A |
| | | 4 | serious |
| | | 5 | quasi-serious |
| | | 6 | contractor responsibility |
| | | 8 | responsible incident, rank B |
| | | 9 | others |
| | | | |
| 2 | accident feature 2 | 1 | accident on track blockade |
| | | 2 | accident on use of maintenance vehicle |
| 3 | ditto | 3 | accident on use of trolley |
| | | 4 | accident due to home signal overrun |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 5 | accident due to shunting signal overrun |
| | | 6 | accident in disordered train schedule |
| | | 7 | miscellaneous warning giving accident |
| | | 10 | accident on signal transfer work |
| | | 11 | accident on maintenence work |
| | | 12 | accident on shunting |
| | | 13 | on way door release accident |
| | | 14 | train separation |
| | | 15 | brake inaction |
| | | 16 | brake inability |
| | | 17 | track circuit failure |
| | | 18 | signal indication error accident |
| | | 19 | accident on substitutive blockade |
| | | 90 | others |
| | | | |
| 4 | branch office | 1 | Morioka |
| | | 2 | Akita |
| | | 3 | Sendai |
| | | 4 | Niigata |
| | | 5 | Takasaki |
| | | 6 | Mito |
| | | 7 | Chiba |
| | | 9 | Tokyo |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 11 | Nagano |
| | | | |
| | | | |
| 5 | accident number | number | Branch office code + year + month + accident number identifies each accident case |
| | | | |
| 6 | year | number | Japanese era named year |
| | | | |
| 7 | ditto | number | |
| | | | |
| 8 | month | number | |
| | | | |
| 9 | day | number | |
| | | | |
| 10 | hour | number | |
| | | | |
| 11 | minute | number | |
| | | | |
| 12 | weather | 1 | sunny |
| | | 2 | cloudy |
| | | 3 | rainy |
| | | 4 | snowy |
| | | 5 | foggy |
| | | 6 | stormy |
| | | 7 | snow stormy |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 8 | typhoon |
| | | 9 | others |
| | | | |
| 13 | branch office | 1-11 | as defined in column 4 |
| | | | |
| 14 | line | number | line name code |
| | | | |
| 15 | station | number | station number |
| | | | |
| 16 | ditto | | ditto |
| | | | |
| 17 | location | 1 | station area |
| | | A | ditto (main down-line) |
| | | B | ditto (main up-line) |
| | | 2 | inter station area |
| | | C | ditto (down-line) |
| | | D | ditto (up-line) |
| | | 3 | station area and inter-station area |
| | | E | ditto (down-line) |
| | | F | ditto (up-line) |
| | | 4 | depot area |
| | | 5 | workshop area |
| | | | |
| 18 | train type | 1 | passenger car train |
| | | 2 | electricity car train |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 3 | diesel car train |
| | | 4 | cargo train |
| | | 5 | mixed train |
| | | 6 | freight train |
| | | 7 | special train |
| | | 8 | single car train |
| | | 9 | shunting car |
| | | 11 | detained car |
| | | 12 | remaining car |
| | | 13 | trolley |
| | | 14 | maintenance car |
| | | 10 | sundry cars |
| | | 90 | others |
| | | | |
| 19 | train number | number | |
| | | | |
| 20 | accident class | 1 | train accident |
| | | | |
| 21 | accident group | 135 | level crossing accident |
| | | | |
| 22 | level crossing type | 11 | grade 1 |
| | | 12 | grade 2 |
| | | 13 | grade 3 |
| | | 14 | grade 4 |
| | | | |
| 23 | accident cause | 31 | intrusion against level |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
| --- | --- | --- | --- |
| | | | crossing gate |
| | | 32 | ignorance of warning |
| | | 33 | impossible traversing |
| | | 34 | side hit |
| | | 35 | clearance invasion |
| | | 36 | wheel wreck |
| | | 37 | engine stalling |
| | | 38 | traffic congestion |
| | | 39 | device trouble |
| | | 40 | level crossing gate inaction |
| | | 90 | others |
| | | | |
| 24 | road traffic | 51 | bus |
| | | 52 | passenger automobile |
| | | 53 | large sized freight truck |
| | | 54 | dump truck, concrete mixer truck |
| | | 55 | ordinary freight truck |
| | | 56 | tricycle automobile |
| | | 57 | special automobile |
| | | 58 | farming automobile |
| | | 59 | motorcycle |
| | | 60 | light vehicle |
| | | 61 | pedestrian |
| | | 62 | others |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 25 | railroad facility factor | 1 | transaction |
| | | 2 | rolling stock |
| | | 3 | infrastructure |
| | | 4 | construction work |
| | | 5 | conflicted factors |
| | | 6 | level crossing |
| | | 7 | sabotage |
| | | 8 | accidental fire |
| | | 9 | natural hazard |
| | | 10 | under investigation |
| | | 11 | transaction (level crossing) |
| | | 90 | others |
| | | | |
| 26 | blank | | |
| | | | |
| 27 | railroad operation factor | 1 | departure |
| | | 2 | arrival |
| | | 3 | turn |
| | | 4 | passage of stops |
| | | 5 | on way into maintenance depot |
| | | 6 | on way out of maintenance depot |
| | | 7 | driving |
| | | 8 | coasting |
| | | 9 | shunting |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 10 | condition watched with attention |
| | | 11 | door in motion |
| | | 12 | on route clearing |
| | | 13 | on control panel watching |
| | | 14 | on monitor panel watching |
| | | 15 | on patrol |
| | | 16 | at work |
| | | 17 | under inspection |
| | | 18 | warning ringing |
| | | 99 | others |
| | | | |
| 28 | phenomenon | 1 | engine inaction |
| | | 2 | engine drive inaction |
| 29 | ditto | 3 | deficient acceleration |
| | | 4 | engine stalling |
| | | 5 | stiffened brake |
| | | 6 | deficient brake force |
| | | 7 | emergency braking |
| | | 8 | ABB, VCB inaction |
| | | 9 | ABB, VCB open |
| | | 10 | circuit braker open |
| | | 11 | reverser trouble |
| | | 12 | switch trouble |
| | | 13 | door trouble |
| | | 14 | flash over |

*continued on next page*

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 15 | MG inaction |
| | | 16 | air pressure deficiency |
| | | 17 | driver's lamp trouble |
| | | 18 | trouble lamp lighting |
| | | 19 | lamp break |
| | | 20 | arc |
| | | 21 | signal indication trouble |
| | | 22 | route release trouble |
| | | 23 | direction setting trouble |
| | | 24 | wrong route release |
| | | 25 | switch operation trouble |
| | | 26 | interlocking trouble |
| | | 27 | control trouble |
| | | 28 | track short circuit |
| | | 29 | track short circuit trouble |
| | | 30 | communication trouble |
| | | 31 | wrong indication |
| | | 32 | erroneous departure indication |
| | | 33 | stop indication |
| | | 34 | level crossing gate inaction, warning inaction |
| | | 35 | functioning of obstruction detector |
| | | 36 | functioning of obstruction warning device |
| | | 37 | special alarm system indication |
| | | 38 | fire tube ignition |
| | | 39 | track distortion |
| | | 40 | lateral distortion of track |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 41 | slope failure |
| | | 42 | road bed cave-in |
| | | 43 | track flooding |
| | | 44 | excess of regulation valve |
| | | 45 | tree fall |
| | | 46 | snow avalanche |
| | | 47 | rock fall |
| | | 48 | power failure |
| | | 49 | contact wire break |
| | | 50 | contact wire slack |
| | | 51 | circuit breaker open |
| | | 52 | blown-in obstacle |
| | | 53 | switch running through |
| | | 54 | derailment due to climbing over on switch |
| | | 55 | derailment due to branching away on switch |
| | | 56 | continuation of operation |
| | | 57 | backward movement without announcement |
| | | 58 | stop sign |
| | | 59 | obstacle detection |
| | | 60 | overturning |
| | | 61 | downfall |
| | | 62 | plunging trespasser |
| | | 63 | lying trespasser |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | 64 | walking trespasser |
| | | 65 | unusual noise |
| | | 66 | unusual odour |
| | | 67 | fire smoking |
| | | 68 | impact |
| | | 69 | clearance invasion |
| | | 99 | others |
| | | | |
| 30 | branch office | 21 | Morioka |
| | | 22 | Akita |
| | | 23 | Sendai |
| | | 30 | Niigata |
| | | 41 | Takasaki |
| | | 42 | Mito |
| | | 43 | Chiba |
| | | 46 | Tokyo |
| | | 51 | Nagano |
| | | | |
| 31 | level crossing code | number | |
| | | | |
| 32 | influence to train operation | 1 | delayed and/or cancelled train |
| hline | | 2 | without influence to train operation |
| | | | |
| 33 | delay time | number | delay time of concerned |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | | train (in min) |
| | | | |
| 34 | cancelled train | 1 | one or more |
| | | 2 | none |
| | | | |
| 35 | number of cancelled trains | number | |
| | | | |
| 36 | number of delayed trains | number | |
| | | | |
| 37 | maximum train delay time | number | in min |
| | | | |
| 38 | total delay time | number | in min |
| | | | |
| 39 | weighting factor | 1 | potential to bear fatalities |
| | | 2 | potential to bear derailment, collision or train fire accident |
| | | 3 | large influence to train schedule |
| | | 4 | with property damage |
| | | 5 | small influence to train schedule |
| | | | |
| 40 | time | 1 | daytime, weekday |
| | | 2 | nighttime, weekday |
| | | 3 | weekend |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| | | | |
| 41 | location | 1 | double track |
| | | 2 | single track (automatic block) |
| | | 3 | single track (non-automatic block) |
| | | | |
| 42 | weather | 1 | sunny or cloudy |
| | | 2 | rainy |
| | | 3 | snowy |
| | | | |
| 43 | cause | 1 | human error |
| | | 2 | device trouble |
| | | 3 | man-induced hazard |
| | | 4 | natural hazard |
| | | | |
| 44 | Io | number | injury (passenger not on board) |
| | | | |
| 45 | Fo | number | fatality (passenger not on board) |
| | | | |
| 46 | Ip | number | injury (passenger on board) |
| | | | |
| 47 | Fp | number | fatality (passenger on board) |
| | | | |
| 48 | It | number | injury (third party person) |
| | | | |
| 49 | Ft | number | fatality (third party person) |
| | | | |
| | | | *continued on next page* |

| Column number | Attribute | Data | Definition |
|---|---|---|---|
| 50 | Iw | number | injury (sub-worker) |
| | | | |
| 51 | Fw | number | fatality (sub-worker) |
| | | | |
| 52 | Ie1 | number | injury (employee) |
| | | | |
| 53 | Fe1 | number | fatality (employee) |
| | | | |
| 54 | Ie2 | number | injury (employee, not on duty) |
| | | | |
| 55 | Fe2 | number | fatality (employee, not on duty) |
| | | | |
| 56 | I(sum) | number | injury (total) |
| | | | |
| 57 | F(sum) | number | fatality (total) |

# Appendix C

# Risk for crossings by type of safety device and road traffic

This appendix shows the accident rate, the weighted consequences per accident and the monetary collective risk $R_m$ for crossings grouped on the basis of the type of safety device and the road traffic involved in the accident. It details the schematic diagram shown in Figure 3-27. The following tables use the legends shown below:

1. #LC: Number of level crossings

2. #ACC: Number of accidents

3. $p$: Accident rate (per million trains)

4. $w$: Weighted consequences per accident

5. $R_m$: Monetary collective risk (million yen)

## C.1 Crossings with automatic barrier and without obstacle detector

This section shows the accident rate and the monetary collective risk for crossings equipped with automatic barrier but without obstcale detector.

### C.1.1 Automobile traffic

| RTV | Automobile traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 79 | 0 | 0 | 0 | 0 |
| 20-40 | 339 | 10 | 0.45 | 6.50 | 2.91 |
| 40-60 | 176 | 3 | 0.16 | 17.67 | 2.75 |
| 60-80 | 157 | 3 | 0.12 | 12.67 | 1.58 |
| 80-100 | 58 | 1 | 0.09 | 33 | 2.88 |
| 100-120 | 98 | 4 | 0.17 | 34 | 5.76 |
| 120-160 | 45 | 3 | 0.22 | 132.67 | 28.85 |
| 160-200 | 18 | 2 | 0.28 | 297.5 | 83.9 |
| 200-400 | 32 | 1 | 0.05 | 245 | 11.65 |

| RTV | Automobile traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 112 | 0 | 0 | 0 | 0 |
| 20-40 | 378 | 4 | 0.17 | 9.75 | 1.57 |
| 40-60 | 175 | 5 | 0.26 | 6.60 | 1.72 |
| 60-80 | 142 | 5 | 0.23 | 25.40 | 5.83 |
| 80-100 | 61 | 2 | 0.17 | 118 | 19.63 |
| 100-120 | 86 | 5 | 0.24 | 17.4 | 4.20 |
| 120-160 | 80 | 4 | 0.16 | 80.50 | 13.13 |
| 160-200 | 44 | 6 | 0.35 | 32.17 | 11.13 |
| 200-400 | 28 | 0 | 0 | 0 | 0 |

| RTV | Automobile traffic volume: 1000-5000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 46 | 1 | 0.99 | 2 | 1.98 |
| 20-40 | 166 | 9 | 0.83 | 20 | 16.50 |
| 40-60 | 55 | 2 | 0.33 | 6.50 | 2.16 |
| 60-80 | 48 | 1 | 0.14 | 35 | 4.76 |
| 80-100 | 22 | 0 | 0 | 0 | 0 |
| 100-120 | 25 | 0 | 0 | 0 | 0 |
| 120-160 | 28 | 3 | 0.35 | 32 | 11.20 |
| 160-200 | 33 | 9 | 0.69 | 30.67 | 21.22 |
| 200-400 | 21 | 4 | 0.29 | 79.50 | 23.09 |

| RTV | Automobile traffic volume: 5000-10000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 5 | 1 | 9.1 | 5 | 45.5 |
| 20-40 | 27 | 4 | 2.3 | 2.5 | 5.75 |
| 40-60 | 16 | 0 | 0 | 0 | 0 |
| 60-80 | 6 | 0 | 0 | 0 | 0 |
| 80-100 | 3 | 2 | 3.38 | 14.5 | 49.01 |
| 100-120 | 3 | 0 | 0 | 0 | 0 |
| 120-160 | 2 | 0 | 0 | 0 | 0 |
| 160-200 | 2 | 0 | 0 | 0 | 0 |
| 200-400 | 6 | 3 | 0.76 | 82 | 62.32 |

### C.1.2 Freight truck traffic

| RTV | Freight truck traffic volume: 0-50 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 144 | 1 | 0.32 | 26 | 8.25 |
| 20-40 | 340 | 3 | 0.13 | 13 | 1.69 |
| 40-60 | 137 | 1 | 0.07 | 0 | 0 |
| 60-80 | 97 | 1 | 0.07 | 1 | 0.07 |
| 80-100 | 31 | 0 | 0 | 0 | 0 |
| 100-120 | 84 | 0 | 0 | 0 | 0 |
| 120-160 | 49 | 2 | 0.13 | 13 | 1.69 |
| 160-200 | 25 | 0 | 0 | 0 | 0 |
| 200-400 | 13 | 0 | 0 | 0 | 0 |

| RTV | Freight truck traffic volume: 50-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 10 | 0 | 0 | 0 | 0 |
| 20-40 | 47 | 1 | 0.32 | 2 | 0.64 |
| 40-60 | 17 | 0 | 0 | 0 | 0 |
| 60-80 | 8 | 0 | 0 | 0 | 0 |
| 80-100 | 5 | 0 | 0 | 0 | 0 |
| 100-120 | 4 | 0 | 0 | 0 | 0 |
| 120-160 | 5 | 1 | 0.65 | 6 | 3.90 |
| 160-200 | 5 | 0 | 0 | 0 | 0 |
| 200-400 | 6 | 0 | 0 | 0 | 0 |

| RTV | Freight truck traffic volume: 100-200 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 7 | 0 | 0 | 0 | 0 |
| 20-40 | 43 | 0 | 0 | 0 | 0 |
| 40-60 | 9 | 0 | 0 | 0 | 0 |
| 60-80 | 10 | 0 | 0 | 0 | 0 |
| 80-100 | 2 | 0 | 0 | 0 | 0 |
| 100-120 | 4 | 0 | 0 | 0 | 0 |
| 120-160 | 4 | 0 | 0 | 0 | 0 |
| 160-200 | 4 | 1 | 0.63 | 2 | 1.26 |
| 200-400 | 2 | 0 | 0 | 0 | 0 |

| RTV | Freight truck traffic volume: >200 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 13 | 0 | 0 | 0 | 0 |
| 20-40 | 39 | 0 | 0 | 0 | 0 |
| 40-60 | 12 | 2 | 1.52 | 19.5 | 29.64 |
| 60-80 | 9 | 1 | 0.73 | 2 | 1.46 |
| 80-100 | 5 | 0 | 0 | 0 | 0 |
| 100-120 | 5 | 0 | 0 | 0 | 0 |
| 120-160 | 2 | 0 | 0 | 0 | 0 |
| 160-200 | 7 | 0 | 0 | 0 | 0 |
| 200-400 | 1 | 0 | 0 | 0 | 0 |

### C.1.3 Motorcycle traffic

| RTV | Motorcycle traffic volume: 0-50 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 190 | 0 | 0 | 0 | 0 |
| 20-40 | 528 | 3 | 0.09 | 34.67 | 3.12 |
| 40-60 | 283 | 1 | 0.03 | 101 | 3.26 |
| 60-80 | 261 | 1 | 0.03 | 101 | 2.52 |
| 80-100 | 76 | 0 | 0 | 0 | 0 |
| 100-120 | 147 | 1 | 0.03 | 6 | 0.18 |
| 120-160 | 92 | 0 | 0 | 0 | 0 |
| 160-200 | 42 | 1 | 0.06 | 105 | 6.34 |
| 200-400 | 40 | 0 | 0 | 0 | 0 |

| RTV | Motorcycle traffic volume: 50-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 37 | 0 | 0 | 0 | 0 |
| 20-40 | 136 | 0 | 0 | 0 | 0 |
| 40-60 | 53 | 0 | 0 | 0 | 0 |
| 60-80 | 62 | 1 | 0.11 | 2 | 0.22 |
| 80-100 | 22 | 0 | 0 | 0 | 0 |
| 100-120 | 29 | 0 | 0 | 0 | 0 |
| 120-160 | 37 | 0 | 0 | 0 | 0 |
| 160-200 | 19 | 0 | 0 | 0 | 0 |
| 200-400 | 16 | 0 | 0 | 0 | 0 |

| RTV | Motorcycle traffic volume: >100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 31 | 0 | 0 | 0 | 0 |
| 20-40 | 135 | 0 | 0 | 0 | 0 |
| 40-60 | 44 | 0 | 0 | 0 | 0 |
| 60-80 | 37 | 0 | 0 | 0 | 0 |
| 80-100 | 15 | 0 | 0 | 0 | 0 |
| 100-120 | 26 | 0 | 0 | 0 | 0 |
| 120-160 | 23 | 1 | 0.14 | 0 | 0 |
| 160-200 | 30 | 0 | 0 | 0 | 0 |
| 200-400 | 33 | 1 | 0.05 | 61 | 2.82 |

### C.1.4 Light vehicle traffic

| RTV | Light vehicle traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 166 | 1 | 0.28 | 103 | 28.33 |
| 20-40 | 479 | 2 | 0.06 | 2.5 | 0.15 |
| 40-60 | 249 | 4 | 0.15 | 11 | 1.61 |
| 60-80 | 274 | 0 | 0 | 0 | 0 |
| 80-100 | 76 | 1 | 0.07 | 2 | 0.14 |
| 100-120 | 138 | 0 | 0 | 0 | 0 |
| 120-160 | 87 | 0 | 0 | 0 | 0 |
| 160-200 | 51 | 1 | 0.05 | 32 | 1.59 |
| 200-400 | 33 | 0 | 0 | 0 | 0 |

| RTV | Light vehicle traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 77 | 0 | 0 | 0 | 0 |
| 20-40 | 348 | 0 | 0 | 0 | 0 |
| 40-60 | 132 | 1 | 0.07 | 3 | 0.21 |
| 60-80 | 112 | 0 | 0 | 0 | 0 |
| 80-100 | 34 | 0 | 0 | 0 | 0 |
| 100-120 | 74 | 0 | 0 | 0 | 0 |
| 120-160 | 63 | 0 | 0 | 0 | 0 |
| 160-200 | 41 | 2 | 0.12 | 102 | 12.56 |
| 200-400 | 35 | 0 | 0 | 0 | 0 |

| RTV | Light vehicle traffic volume: 1000-5000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 8 | 0 | 0 | 0 | 0 |
| 20-40 | 16 | 0 | 0 | 0 | 0 |
| 40-60 | 6 | 0 | 0 | 0 | 0 |
| 60-80 | 1 | 0 | 0 | 0 | 0 |
| 80-100 | 6 | 0 | 0 | 0 | 0 |
| 100-120 | 3 | 0 | 0 | 0 | 0 |
| 120-160 | 4 | 0 | 0 | 0 | 0 |
| 160-200 | 5 | 0 | 0 | 0 | 0 |
| 200-400 | 6 | 2 | 0.51 | 63.5 | 32.22 |

### C.1.5 Pedestrian traffic

| RTV | Pedestrian traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 149 | 0 | 0 | 0 | 0 |
| 20-40 | 540 | 1 | 0.03 | 108 | 3.04 |
| 40-60 | 315 | 1 | 0.03 | 0 | 0 |
| 60-80 | 306 | 1 | 0.02 | 103 | 2.20 |
| 80-100 | 114 | 2 | 0.09 | 107.5 | 9.57 |
| 100-120 | 147 | 0 | 0 | 0 | 0 |
| 120-160 | 119 | 0 | 0 | 0 | 0 |
| 160-200 | 77 | 2 | 0.07 | 100 | 7.00 |
| 200-400 | 86 | 0 | 0 | 0 | 0 |

| RTV | Pedestrian traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 102 | 0 | 0 | 0 | 0 |
| 20-40 | 407 | 2 | 0.08 | 52.5 | 3.93 |
| 40-60 | 136 | 0 | 0 | 0 | 0 |
| 60-80 | 89 | 1 | 0.07 | 11 | 0.77 |
| 80-100 | 59 | 0 | 0 | 0 | 0 |
| 100-120 | 97 | 2 | 0.09 | 0 | 0 |
| 120-160 | 61 | 3 | 0.16 | 72 | 11.55 |
| 160-200 | 46 | 0 | 0 | 0 | 0 |
| 200-400 | 71 | 2 | 0.04 | 102 | 4.37 |

| RTV | Pedestrian traffic volume: 1000-5000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 8 | 0 | 0 | 0 | 0 |
| 20-40 | 11 | 0 | 0 | 0 | 0 |
| 40-60 | 4 | 0 | 0 | 0 | 0 |
| 60-80 | 3 | 0 | 0 | 0 | 0 |
| 80-100 | 6 | 0 | 0 | 0 | 0 |
| 100-120 | 8 | 0 | 0 | 0 | 0 |
| 120-160 | 9 | 0 | 0 | 0 | 0 |
| 160-200 | 9 | 0 | 0 | 0 | 0 |
| 200-400 | 12 | 1 | 0.13 | 0 | 0 |

## C.2 Crossings with semiautomatic automatic barrier and without obstacle detector

### C.2.1 Automobile traffic

| RTV | Automobile traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 13 | 1 | 3.51 | 1 | 3.51 |
| 20-40 | 93 | 2 | 0.32 | 9 | 2.88 |
| 40-60 | 87 | 1 | 0.10 | 1 | 0.10 |
| 60-80 | 99 | 0 | 0 | 0 | 0 |
| 80-100 | 59 | 1 | 0.09 | 0 | 0 |
| 100-120 | 83 | 5 | 0.25 | 162.2 | 40.55 |
| 120-160 | 42 | 1 | 0.08 | 2 | 0.16 |
| 160-200 | 11 | 0 | 0 | 0 | 0 |
| 200-400 | 25 | 2 | 0.12 | 30 | 3.60 |

| RTV | Automobile traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 28 | 0 | 0 | 0 | 0 |
| 20-40 | 163 | 4 | 0.37 | 39 | 14.43 |
| 40-60 | 127 | 8 | 0.58 | 18.63 | 10.81 |
| 60-80 | 179 | 5 | 0.18 | 3.20 | 0.58 |
| 80-100 | 87 | 7 | 0.41 | 108.71 | 44.57 |
| 100-120 | 85 | 4 | 0.20 | 29 | 5.80 |
| 120-160 | 71 | 5 | 0.23 | 35.6 | 8.19 |
| 160-200 | 41 | 1 | 0.06 | 2 | 0.12 |
| 200-400 | 41 | 7 | 0.26 | 52.14 | 13.56 |

| RTV | Automobile traffic volume: 1000-5000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 0 | 0 | 0 | 0 | 0 |
| 20-40 | 104 | 4 | 0.59 | 2 | 1.18 |
| 40-60 | 99 | 5 | 0.46 | 4.2 | 1.93 |
| 60-80 | 123 | 10 | 0.53 | 5.7 | 3.02 |
| 80-100 | 60 | 4 | 0.34 | 4.25 | 1.45 |
| 100-120 | 64 | 6 | 0.39 | 37 | 14.43 |
| 120-160 | 62 | 6 | 0.32 | 18.67 | 5.97 |
| 160-200 | 35 | 5 | 0.36 | 46.6 | 16.78 |
| 200-400 | 48 | 5 | 0.16 | 4.40 | 0.70 |

| RTV | Automobile traffic volume: 5000-10000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 7 | 0 | 0 | 0 | 0 |
| 20-40 | 25 | 0 | 0 | 0 | 0 |
| 40-60 | 33 | 0 | 0 | 0 | 0 |
| 60-80 | 28 | 4 | 0.93 | 46.75 | 43.48 |
| 80-100 | 6 | 0 | 0 | 0 | 0 |
| 100-120 | 6 | 2 | 1.38 | 8.5 | 11.73 |
| 120-160 | 7 | 1 | 0.47 | 38 | 17.71 |
| 160-200 | 5 | 1 | 0.51 | 78 | 39.57 |
| 200-400 | 8 | 2 | 0.38 | 31 | 11.78 |

### C.2.2 Freight truck traffic

| RTV | Freight truck traffic volume: 0-50 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 33 | 0 | 0 | 0 | 0 |
| 20-40 | 133 | 0 | 0 | 0 | 0 |
| 40-60 | 106 | 4 | 0.34 | 5.25 | 1.79 |
| 60-80 | 127 | 1 | 0.05 | 0 | 0 |
| 80-100 | 54 | 0 | 0 | 0 | 0 |
| 100-120 | 100 | 1 | 0.04 | 4 | 0.16 |
| 120-160 | 62 | 4 | 0.21 | 41 | 8.61 |
| 160-200 | 27 | 1 | 0.09 | 10 | 0.90 |
| 200-400 | 24 | 0 | 0 | 0 | 0 |

| RTV | Freight truck traffic volume: 50-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 5 | 0 | 0 | 0 | 0 |
| 20-40 | 29 | 0 | 0 | 0 | 0 |
| 40-60 | 21 | 2 | 0.87 | 1 | 0.87 |
| 60-80 | 27 | 1 | 0.24 | 1 | 0.24 |
| 80-100 | 3 | 0 | 0 | 0 | 0 |
| 100-120 | 11 | 0 | 0 | 0 | 0 |
| 120-160 | 10 | 0 | 0 | 0 | 0 |
| 160-200 | 1 | 0 | 0 | 0 | 0 |
| 200-400 | 6 | 0 | 0 | 0 | 0 |

### C.2.3 Motorcycle traffic

| RTV | Motorcycle traffic volume: 0-50 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 98 | 3 | 1.39 | 39 | 54.21 |
| 20-40 | 202 | 3 | 0.23 | 70.33 | 16.18 |
| 40-60 | 75 | 0 | 0 | 0 | 0 |
| 60-80 | 51 | 4 | 0.51 | 36.25 | 18.49 |
| 80-100 | 21 | 1 | 0.24 | 107 | 25.85 |
| 100-120 | 22 | 1 | 0.19 | 1 | 0.19 |
| 120-160 | 10 | 0 | 0 | 0 | 0 |
| 160-200 | 0 | 0 | 0 | | 0 |
| 200-400 | 1 | 0 | 0 | 0 | 0 |

### C.2.4 Light vehicle traffic

| RTV | Light vehicle traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 24 | 0 | 0 | 0 | 0 |
| 20-40 | 134 | 0 | 0 | 0 | 0 |
| 40-60 | 145 | 0 | 0 | 0 | 0 |
| 60-80 | 187 | 0 | 0 | 0 | 0 |
| 80-100 | 68 | 0 | 0 | 0 | 0 |
| 100-120 | 123 | 0 | 0 | 0 | 0 |
| 120-160 | 49 | 0 | 0 | 0 | 0 |
| 160-200 | 24 | 0 | 0 | 0 | 0 |
| 200-400 | 29 | 1 | 0.05 | 15 | 0.75 |

| RTV | Light vehicle traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 32 | 0 | 0 | 0 | 0 |
| 20-40 | 194 | 0 | 0 | 0 | 0 |
| 40-60 | 155 | 1 | 0.06 | 6 | 0.36 |
| 60-80 | 256 | 3 | 0.08 | 38 | 2.91 |
| 80-100 | 102 | 2 | 0.09 | 3.50 | 3.48 |
| 100-120 | 115 | 1 | 0.04 | 2 | 0.08 |
| 120-160 | 99 | 4 | 0.13 | 35 | 4.61 |
| 160-200 | 60 | 2 | 0.09 | 57 | 4.82 |
| 200-400 | 59 | 4 | 0.10 | 53.75 | 5.55 |

| RTV | Light vehicle traffic volume: 1000-5000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 5 | 0 | 0 | 0 | 0 |
| 20-40 | 25 | 1 | 0.61 | 1 | 0.61 |
| 40-60 | 32 | 0 | 0 | 0 | 0 |
| 60-80 | 26 | 0 | 0 | 0 | 0 |
| 80-100 | 11 | 1 | 0.46 | 107 | 49.35 |
| 100-120 | 9 | 1 | 0.46 | 1 | 0.46 |
| 120-160 | 18 | 0 | 0 | 0 | 0 |
| 160-200 | 14 | 0 | 0 | 0 | 0 |
| 200-400 | 40 | 2 | 0.08 | 13.5 | 1.03 |

### C.2.5 Pedestrian traffic

| RTV | Pedestrian traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 14 | 0 | 0 | 0 | 0 |
| 20-40 | 138 | 1 | 0.11 | 102 | 11.25 |
| 40-60 | 164 | 0 | 0 | 0 | 0 |
| 60-80 | 251 | 0 | 0 | 0 | 0 |
| 80-100 | 117 | 2 | 0.09 | 107.50 | 9.32 |
| 100-120 | 126 | 0 | 0 | 0 | 0 |
| 120-160 | 85 | 1 | 0.04 | 4 | 0.16 |
| 160-200 | 53 | 2 | 0.10 | 103.50 | 9.91 |
| 200-400 | 85 | 2 | 0.04 | 106.50 | 3.81 |

| RTV | Pedestrian traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 44 | 0 | 0 | 0 | 0 |
| 20-40 | 233 | 1 | 0.07 | 3 | 0.21 |
| 40-60 | 188 | 0 | 0 | 0 | 0 |
| 60-80 | 224 | 1 | 0.03 | 103 | 2.99 |
| 80-100 | 104 | 1 | 0.05 | 103 | 5.03 |
| 100-120 | 140 | 0 | 0 | 0 | 0 |
| 120-160 | 111 | 4 | 0.12 | 0.50 | 0.06 |
| 160-200 | 59 | 1 | 0.04 | 205 | 8.81 |
| 200-400 | 114 | 4 | 0.05 | 82 | 4.38 |

| RTV | Pedestrian traffic volume: 1000-5000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 13 | 0 | 0 | 0 | 0 |
| 20-40 | 36 | 0 | 0 | 0 | 0 |
| 40-60 | 27 | 0 | 0 | 0 | 0 |
| 60-80 | 21 | 0 | 0 | 0 | 0 |
| 80-100 | 16 | 0 | 0 | 0 | 0 |
| 100-120 | 18 | 0 | 0 | 0 | 0 |
| 120-160 | 19 | 0 | 0 | 0 | 0 |
| 160-200 | 12 | 1 | 0.21 | 5 | 1.05 |
| 200-400 | 19 | 1 | 0.08 | 0 | 0 |

## C.3 Grade 3 crossings without obstacle detector

### C.3.1 Automobile traffic

| RTV | Automobile traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 26 | 1 | 0.04 | 16 | 0.64 |
| 20-40 | 38 | 0 | 0 | 0 | 0 |
| 40-60 | 27 | 5 | 1.69 | 16.80 | 28.41 |
| 60-80 | 13 | 1 | 0.50 | 10 | 5 |
| 80-100 | 3 | 0 | 0 | 0 | 0 |
| 100-120 | 8 | 2 | 1.04 | 51.50 | 53.45 |
| 120-160 | 4 | 0 | 0 | 0 | 0 |
| 160-200 | 0 | 0 | 0 | 0 | 0 |
| 200-400 | 2 | 0 | 0 | 0 | 0 |

| RTV | Automobile traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 12 | 1 | 3.81 | 1 | 3.81 |
| 20-40 | 2 | 0 | 0 | 0 | 0 |
| 40-60 | 0 | 0 | 0 | 0 | 0 |
| 60-80 | 0 | 0 | 0 | 0 | 0 |
| 80-100 | 0 | 0 | 0 | 0 | 0 |
| 100-120 | 0 | 0 | 0 | 0 | 0 |
| 120-160 | 0 | 0 | 0 | 0 | 0 |
| 160-200 | 0 | 0 | 0 | 0 | 0 |
| 200-400 | 0 | 0 | 0 | 0 | 0 |

### C.3.2 Light vehicle traffic

| RTV | Light vehicle traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 48 | 0 | 0 | 0 | 0 |
| 20-40 | 67 | 0 | 0 | 0 | 0 |
| 40-60 | 50 | 1 | 0.18 | 3 | 0.54 |
| 60-80 | 25 | 0 | 0 | 0 | 0 |
| 80-100 | 6 | 0 | 0 | 0 | 0 |
| 100-120 | 25 | 0 | 0 | 0 | 0 |
| 120-160 | 17 | 0 | 0 | 0 | 0 |
| 160-200 | 9 | 0 | 0 | 0 | 0 |
| 200-400 | 8 | 1 | 0.19 | 80 | 15.22 |

| RTV | Light vehicle traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 6 | 0 | 0 | 0 | 0 |
| 20-40 | 8 | 0 | 0 | 0 | 0 |
| 40-60 | 7 | 1 | 1.31 | 4 | 5.24 |
| 60-80 | 6 | 0 | 0 | 0 | 0 |
| 80-100 | 0 | 0 | 0 | 0 | 0 |
| 100-120 | 4 | 0 | 0 | 0 | 0 |
| 120-160 | 4 | 1 | 0.81 | 3 | 2.43 |
| 160-200 | 0 | 0 | 0 | 0 | 0 |
| 200-400 | 0 | 0 | 0 | 0 | 0 |

## C.3.3 Pedestrian traffic

| RTV | Pedestrian traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 41 | 0 | 0 | 0 | 0 |
| 20-40 | 60 | 0 | 0 | 0 | 0 |
| 40-60 | 41 | 0 | 0 | 0 | 0 |
| 60-80 | 21 | 0 | 0 | 0 | 0 |
| 80-100 | 13 | 0 | 0 | 0 | 0 |
| 100-120 | 24 | 1 | 0.17 | 122 | 21.10 |
| 120-160 | 20 | 1 | 0.16 | 101 | 16.47 |
| 160-200 | 5 | 0 | 0 | 0 | 0 |
| 200-400 | 8 | 0 | 0 | 0 | 0 |

| RTV | Pedestrian traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 21 | 0 | 0 | 0 | 0 |
| 20-40 | 26 | 1 | 0.59 | 106 | 62.05 |
| 40-60 | 19 | 3 | 1.44 | 37.67 | 54.31 |
| 60-80 | 12 | 0 | 0 | 0 | 0 |
| 80-100 | 4 | 0 | 0 | 0 | 0 |
| 100-120 | 11 | 0 | 0 | 0 | 0 |
| 120-160 | 9 | 1 | 0.36 | 147 | 53.27 |
| 160-200 | 8 | 1 | 0.32 | 1 | 0.32 |
| 200-400 | 7 | 1 | 0.22 | 103 | 22.40 |

## C.4 Grade 4 crossings without obstacle detector

### C.4.1 Automobile traffic

| RTV | Automobile traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 32 | 0 | 0 | 0 | 0 |
| 20-40 | 70 | 7 | 1.52 | 35.43 | 53.85 |
| 40-60 | 22 | 2 | 0.83 | 122.50 | 101.68 |
| 60-80 | 11 | 0 | 0 | 0 | 0 |
| 80-100 | 3 | 0 | 0 | 0 | 0 |
| 100-120 | 1 | 0 | 0 | 0 | 0 |
| 120-160 | 1 | 0 | 0 | 0 | 0 |
| 160-200 | 0 | 0 | 0 | 0 | 0 |
| 200-400 | 0 | 0 | 0 | 0 | 0 |

### C.4.2 Motorcycle traffic

| RTV | Motorcycle traffic volume: 0-50 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 98 | 3 | 1.39 | 39 | 54.21 |
| 20-40 | 202 | 3 | 0.23 | 70.33 | 16.18 |
| 40-60 | 75 | 0 | 0 | 0 | 0 |
| 60-80 | 51 | 4 | 0.51 | 36.25 | 18.49 |
| 80-100 | 21 | 1 | 0.24 | 107 | 25.85 |
| 100-120 | 22 | 1 | 0.19 | 1 | 0.19 |
| 120-160 | 10 | 0 | 0 | 0 | 0 |
| 160-200 | 0 | 0 | 0 | 0 | 0 |
| 200-400 | 1 | 0 | 0 | 0 | 0 |

### C.4.3 Light vehicle traffic

| RTV | Light vehicle traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 108 | 0 | 0 | 0 | 0 |
| 20-40 | 227 | 4 | 0.27 | 62.75 | 16.83 |
| 40-60 | 83 | 1 | 0.11 | 118 | 12.98 |
| 60-80 | 58 | 0 | 0 | 0 | 0 |
| 80-100 | 26 | 0 | 0 | 0 | 0 |
| 100-120 | 22 | 0 | 0 | 0 | 0 |
| 120-160 | 10 | 0 | 0 | 0 | 0 |
| 160-200 | 2 | 0 | 0 | 0 | 0 |
| 200-400 | 2 | 0 | 0 | 0 | 0 |

### C.4.4 Pedestrian traffic

| RTV | Pedestrian traffic volume: 0-100 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 113 | 0 | 0 | 0 | 0 |
| 20-40 | 288 | 2 | 0.11 | 108 | 11.42 |
| 40-60 | 115 | 5 | 0.40 | 88.60 | 35.18 |
| 60-80 | 69 | 2 | 0.19 | 2 | 0.38 |
| 80-100 | 41 | 0 | 0 | 0 | 0 |
| 100-120 | 34 | 0 | 0 | 0 | 0 |
| 120-160 | 16 | 0 | 0 | 0 | 0 |
| 160-200 | 7 | 0 | 0 | 0 | 0 |
| 200-400 | 7 | 0 | 0 | 0 | 0 |

| RTV | Pedestrian traffic volume: 100-1000 | | | | |
|---|---|---|---|---|---|
| | #LC | #ACC | $p$ | $w$ | $R_m$ |
| 0-20 | 17 | 0 | 0 | 0 | 0 |
| 20-40 | 30 | 2 | 1.02 | 54.50 | 55.32 |
| 40-60 | 16 | 0 | 0 | 0 | 0 |
| 60-80 | 3 | 0 | 0 | 0 | 0 |
| 80-100 | 6 | 1 | 0.85 | 105 | 88.79 |
| 100-120 | 2 | 0 | 0 | 0 | 0 |
| 120-160 | 6 | 0 | 0 | 0 | 0 |
| 160-200 | 0 | 0 | 0 | 0 | 0 |
| 200-400 | 1 | 1 | 1.52 | 101 | 153.73 |

# Appendix D

# Testing the statistical significance of various level crossing attributes

This appendix describes tests conducted to determine the statistical significance of various level crossing attributes. Specifically, three crossing attributes are discussed below:

1. Visibility of the crossing (as described in Section 3.7.1)

2. Road gradient (as described in Section 3.7.2)

3. Crossings equipped with obstacle detector (as described in Section 3.7.5)

## D.1 Framework

The occurrence of accidents at a level crossing can be described by a Bernoulli random variable $X$, given as

$$X_i = \begin{cases} 1 & \text{if accident occurs at crossing } i \\ 0 & \text{otherwise} \end{cases}$$

$$X_i = \begin{cases} 1 & \text{with probability } p \\ 0 & \text{with probability } q = (1-p) \end{cases}$$

The sum of $n$ independent Bernoulli random variables $X_1, X_2, \ldots, X_n$ is a Binomial random variable with mean $np$ and variance $npq$. Since our definition of the accident rate $p$ is the number of accidents per million trains, and on average, $p$ is around 0.5, the value of $q$ is approximately equal to 1. Thus, the number of accidents follows a Binomial distribution with mean $np$ and variance $np$ (Here, $n$ refers to the number of trains going across the crossing and $p$ is the accident rate).

## D.2 Visibility of the crossing

The mean accident rate for crossings with less than 20m visibility is 0.705 (per million trains) and there have been 220 accidents in this category. On the other hand, the mean accident rate for crossings with greater than 20m visibility is 0.509 (per million trains) with 707 accidents in this category. For crossings with visibility less than 20m:

$$Mean = np = 312 \times 10^6 \times 0.705 = 220 \tag{D.1}$$

$$Variance = \sigma^2 = np = 220 \tag{D.2}$$

$$\Rightarrow Deviation = \sigma = \sqrt{220} \approx 15 \tag{D.3}$$

For crossings with greater than 20m visibility:

$$Mean = np = 1389 \times 10^6 \times 0.509 = 707 \tag{D.4}$$

$$Variance = \sigma^2 = np = 707 \tag{D.5}$$

$$\Rightarrow Deviation = \sigma = \sqrt{707} \approx 27 \tag{D.6}$$

If the accident rate $p$ were 0.705 (instead of 0.509), then $np = 979$ accidents which is almost $10\sigma$ away from 707. This is clearly statistically significant.

## D.3 Road gradient

The mean accident rate for crossings with level road gradient is 0.427 (per million trains) with 206 accidents in this category. The mean accident rate for crossings with upward or downward gradient is 0.550 (per million trains) with 721 accidents in this category. For crossings with level road gradient:

$$Mean = np = 206 \tag{D.7}$$

$$Variance = \sigma^2 = np = 206 \tag{D.8}$$

$$\Rightarrow Deviation = \sigma = \sqrt{206} \approx 14 \tag{D.9}$$

For crossings with upward or downward gradient:

$$Mean = np = 721 \tag{D.10}$$

$$Variance = \sigma^2 = np = 721 \tag{D.11}$$

$$\Rightarrow Deviation = \sigma \approx 27 \tag{D.12}$$

If $p$ were 0.427 (instead of 0.550), then $np = 560$ accidents which is almost $6\sigma$ away from 721, which is statistically significant.

## D.4 Crossings equipped with obstacle detectors

The average accident rate for crossings without detectors is 0.428 (per million trains) with a total of 811 accidents and the mean rate for crossings with detectors is 0.123

(per million trains) with 116 accidents. For crossings without detectors:

$$Meanaccidents = np = 811 \tag{D.13}$$

$$Variance = \sigma^2 = 811 \tag{D.14}$$

$$\Rightarrow Deviation = \sigma \approx 28 \tag{D.15}$$

For crossings with detectors:

$$Meanaccidents = np = 116 \tag{D.16}$$

$$Variance = \sigma^2 = 116 \tag{D.17}$$

$$\Rightarrow Deviation = \sigma \approx 11 \tag{D.18}$$

If the accident rate $p$ were 0.428 (instead of 0.123), then $np = 404$ accidents which is almost $37\sigma$ away from 116 and is highly statistically significant.